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A COMPARISON OF TREADMILL AND OVERGROUND RUNNING USING EMG AND CINEMATOGRAPHY

by

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ABSTRACT

The purpose of this study was to critically analyse treadmill and overground running performances for the same individual.

The speeds of 5, 9, and 11 mph were used for both overground and treadmill running.

The dependent variables used in the examination and comparison of one running stride from each of the six conditions of running were: (1) timing and duration of muscle action potentials generated from three leg muscles, (2) hip, knee, and ankle angles, and (3) vertical and horizontal displacement of the total body's center of gravity.

The independent variables were: (1) running speed, and (2) manner of running (i.e. treadmill or overground).

The following are the main results of the study: (1) stride frequency was greater and stride length was less for treadmill running, (2) a trend for greater percent time in contact with the running surface for treadmill running as compared to overground running was observed. This difference was observed to increase with running speed, (3) vertical fluctuation of the subject's center of gravity was greater for overground running, as compared to treadmill running at all three speeds. For both treadmill running and overground running, the degree of vertical fluctuation tended to decrease as the running speed increased, (4) hip flexion

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at the end of the forward swing was greater for overground running. This effect increased with running speed, (5) hip extension during follow through was greater for overground running as compared to treadmill running, (6) knee flexion during the forward swing phase was greater for overground running, (7) knee extension during take-off phase was greater for overground running, (8) for both overground and treadmill running at take-off, the initiation of hip extension preceded the initiation of knee extension, which in turn preceded the initiation of ankle extension, (9) for both treadmill and overground running, maximum knee flexion was attained during the forward swing. At the end of forward swing, when maximum hip flexion occurred, the knee had already begun to extend, (10) for both treadmill and overground running, the muscular activation of biceps femoris, vastus medialis, and gastrocnemius commenced simultaneously, (11) for both treadmill and overground running at the speeds of 9 and 11 mph, the electrical activity of vastus medialis and gastrocnemius tended to terminate simultaneously but earlier than biceps femoris. At the speed of 5 mph the termination of electrical activity of these three muscles was simultaneous, (12) biceps femoris was not used to decelerate the thigh during the forward swing stage for overground running. However, in treadmill running, it was used to decelerate the thigh at the end of forward swing, (13) for treadmill running, electrical activity in the three muscles terminated before take-off was completed. For

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overground running the electrical activity of the muscles did not cease until after take-off, (14) the electromyographical pattern produced by gastrocnemius was very similar to the electromyographical pattern of vastus medialis for both overground and treadmill running.

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STATEMENT OF THE PROBLEM

INTRODUCTION

The physical act of running has been under experimental investigation for the last four decades. The early work of Hill (1927), Fenn (1930) and Elftman (1940) was primarily concerned with the rate at which work was done by muscles in running. It was not until the early nineteen-sixties that research workers attempted the arduous task of breaking down the action of running into more meaningful and measureable parameters. These researchers hoped, by examining the parameters that constitute a top rated performance by a runner, to provide the coach with basic physiological, biomechanical and human performance principles from which sound teaching and coaching techniques could be founded.

The main tool of biomechanical research throughout this period was the camera. Through the use of cinematography, experimenters such as Slocum and Bowerman (1962), Deshon and Nelson (1964), Plagenhoef (1971), Hopper (1969), and Sinning and Forsyth (1970), were able to obtain external temporal and spatial measurements of a runner's limbs throughout the total sequence of movement.

One of the major problems of utilizing the informa-

tion gained from these studies is that it is difficult for the coach to observe and correct accurately a runner's movements during the actual event itself. The main reason for this difficulty lies in the fact that the runner is usually moving rapidly with respect to the observing coach. This means that the coach is faced with two major problems. The first is the problem of immediate communication with the runner which would enable him to correct a runner during the actual performance. The second is the problem of accurate observation since the angle of view is continually changing. A simplistic solution to both of these problems would be to have the subject perform on a treadmill in order to learn the proper mechanics of efficient running.

The idea of using a treadmill for the study and training of running is not new. For years treadmill running has been used to investigate physiological stress in human performance. The results of these studies are applied to such diverse fields as space science, cardiac rehabilitation, and conditioning in athletics. Investigators such as Schwartz and Heath (1932), Hubbard (1939), Cavagna et al. (1964), Gollnick and Karpovich (1964), Dill (1965) Ricci et al. (1965), Sinning and Forsyth (1970), Pugh (1970), Myashita et al. (1971), Pugh (1971), Roberts and Alspaugh (1972), and Hoshikawa et al. (1973) have all utilized the treadmill in their studies.

More recently researchers such as Kollias et al.

(1967) and Dal Monte <u>et al</u>. (1973) have been experimenting with the idea of using the treadmill as a training device for runners. The obvious advantages being that the treadmill takes up very little indoor space and is not dependent on climatic conditions. The general hypothesis of these researchers is that a sense of running pace and rhythm gained on the treadmill might be tranferred to running an outdoor course.

The use of the treadmill as an aid to running performance is centered around one major issue. How closely are the mechanics of running on a track duplicated by running on a treadmill? Only two studies, Brookes <u>et al</u>. (1971) and Nelson <u>et al</u>. (1972), could be found in the literature which offered any opinion on the similarity of these two conditions of running. Brookes <u>et al</u>. concluded that no significant biomechanical or physiological differences existed between road and treadmill running. The only criterion they used to base their biomechanical conclusion on was the pattern of lower limb angles throughout one leg cycle. Nelson <u>et al</u>. carried out more extensive film analysis of the two conditions of running. They reported that treadmill running was characterized by longer periods of support, lower vertical velocity, and less variable vertical and horizontal velocities than for overground running.

Both of these studies focused their attention on

the observable external effects which appeared between the two conditions of running. Neither group of investigators sought to establish whether the internal muscular effort and pattern was the same for both conditions of running. In other words, the observable external end result may be the same but the internal causation may differ appreciably.

If the muscular pattern of movement proves to be different for the two conditions of running, one must conclude that the running skill of an individual is not duplicated by running on a treadmill.

PROBLEM

The purpose of this study is to examine whether the muscular pattern, as well as the temporal and spatial relationship of a runner's legs in overground running is duplicated when running on a treadmill.

DELIMITATIONS

1. Evaluation was restricted to the performance of one male subject.

2. Evaluation was further restricted to the analysis of only one stride of the runner's performance at three different speeds. Only the left leg was analysed.

LIMITATIONS

1. The accuracy of determining the subject's center of gravity was limited to the accuracy of Dempster's anatomical data and the ability of the experimenter to locate joint centers.

2. The accuracy of the joint angles measured was limited by the ability of the experimenter to locate joint centers.

3. The results were limited by the accuracy of matching the running speeds of treadmill and overground running.

WORKING DEFINITIONS*

<u>Running Stride</u>

A cycle of motion which starts when one foot strikes the ground and continues until the same foot again strikes the ground.

<u>Support</u>

This is the time the foot strikes the ground with the extremity in the leading position until it leaves the ground from the trailing position.

The support phase is divided into three distinct periods:

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*Slocum, D., and S. James, "Biomechanics of Running," <u>J. American Med. Assoc.</u> CCV, p. 721, 1968

Foot-strike. This is the time when the foot first touches the ground and continues through the brief moment during which the foot becomes firmly fixed.*

Mid-support. This is the period during which the foot is fixed and continues until the heel starts to rise** from the ground.

Take-off. This is the time when the heel starts to rise and continues until the toes leave the running surface.

Recovery

This is the period when the extremity does not bear weight but advances from the trailing position to the leading position in preparation for foot-strike.

Like the support phase, the recovery falls into three functional periods:

Follow-through. This is the time the trailing foot leaves the ground and continues until deceleration of the extremity is complete and forward swing is initiated.

Forward swing. This is the period during which the thigh begins to move forward in the sagittal plane and ends when the hip reaches maximum flexion.

Foot descent. This is the time when maximum flexion of the hip is complete and continues until foot-strike.

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*For this study, the foot was considered to be fixed when it was at a point directly below the body's center of gravity.

**For the cases on the treadmill, where the heel remained off the running surface during the entire support phase, the point of rapid vertical ankle lift was used to mark the end of the mid-support phase.

CHAPTER II

REVIEW OF LITERATURE

EARLY ANALYSIS OF RUNNING

The earliest relevant scientific work, which was concerned with running, was performed by the noted physiologist A. V. Hill (1927). Hill was primarily interested in the energy expenditure of muscle which occurred at different rates of running. It was Hill's opinion that the limiting factor in sprinting speed was the viscosity of the muscles involved. Hill also attempted to develop an empirical equation to account for the velocity curve observed in sprint running.

Following closely behind the work of Hill, were two other physiologists Fenn and Elftman.

Fenn (1930) was primarily concerned with the accounting for the energy expenditure of the muscles involved in running. However, this work required the use of film analysis and it was from these analysis the Fenn was able to offer the opinion that proficient runners tended to raise the knees high as the free swinging leg is recovered.

Elftman's (1940) primary objective was to account for the large energy expenditure which occurred in running. In attempting to find a solution to this problem, Elftman soon became involved in the difficulties of determining muscular force. The early work of Elftman on this subject,

along with its assumptions, has not been greatly improved upon to this day.

Hubbard (1939) was the first researcher to attempt to determine experimentally the action of certain key muscles of the lower limb in relation to movements of running. Hubbard's results were obtained with a pneumatic devise which purportedly was able to detect muscle bulge. Judging from the gross nature of Hubbard's results it would appear that this apparatus was very crude by today's standards. It is of interest to this study to note that Hubbard's subjects were tested on a treadmill so as to keep in range of the apparatus.

In the early nineteen fifties, Henry, (1951) became interested in pursuing the earlier attempt by Hill to develop an equation which would predict the velocity curve of a given runner. It was concluded by Henry that muscle viscosity was not the limiting factor of running speed as was reported by Hill.

BIOMECHANICS OF RUNNING

Overground Studies

It would appear that the true biomechanical study of running began with Slocum and Bowerman (1962). Slocum and Bowerman were primarily concerned with the effect of pelvic posture and lumbar spinal motion during running. From a series of studies, Slocum and Bowerman concluded that an erect trunk posture with a flat back in mid-support was of major importance

for efficient running.

In 1964, Deshon and Nelson published the results of a cinematographical study performed on twenty-nine runners. The purpose of Deshon and Nelson's study was to examine the relationship between a runner's horizontal velocity and: (1) the angle to which the leg is raised in front of the body, (2) length of stride, (3) the angle that the leg makes with the ground at point of touchdown. From the results, Deshon and Nelson concluded that high knee lift, long running stride and placement of the foot as closely beneath the center of gravity of the runner were characteristic of good efficient running. However, the authors do warn that it should not be inferred that these factors 'cause' a performer to run faster.

Slocum and James (1968) published a paper which dealt with the coordination complexities of the lower limbs of a runner. The analysis by Slocum and James was very anatomically detailed in describing what had been visually observed from cinematography. From these visual observations Slocum and James offered kinesiological explanations for the actions observed. Some of the observations by Slocum and James which will be of interest to this study are: (1) that knee flexion is largely passive during the forward swing phase of leg recovery, (2) that the knee is kept acutely flexed until the hip nears full flexion, (3) that the hamstrings decelerate the forward movement of the foot and leg to zero velocity at

a point where the knee is in approximately thirty degrees of flexion and the foot has reached its greatest distance forward of the body, and (4) that during take-off the quadriceps are the prime mover during the early stage of knee extension but as the knee reaches the twenty degree flexed position, extension is augmented by gastrocnemius. The extensory action of the hamstring muscle group is also evident during the latter phase of the knee extension.

These explanations appear to be still accurate today although no one has determined precisely the exact causes underlying efficient running.

Hopper (1969) published a short paper which dealt with the variability of stride rate and stride length with changes in running speed. Hopper concluded that the speed of the driving foot was possibly the limiting factor on a runner's rate of movement.

Treadmill Studies

Sinning and Forsyth (1970) reported from an electro-goniometer study of running on a treadmill that both stride length and leg frequency increased with a runner's velocity. In addition it was found that stride length played the major role at low velocity but that leg frequency became the dominant factor as the runner's velocity increased. From the analysis of running on a treadmill Sinning and Forsyth reported that as the rate of running was increased there was a marked increase in hip flexion but little or no change in hip extension.

Sinning and Forsyth also found during the swing phase knee extension decreased while flexion increased. The overall result was an increase in the amplitude of movement.* Sinning and Forsyth reported that there was no change in ankle flexion and extension when the running velocity was increased.

Nelson and Osterhoudt (1971) investigated the effects that altering the slope and speed would have on the biomechanics of running. Nelson and Osterhoudt concluded from their study that the alterations in both running slope and speed produced significant, predictable changes in stride length, stride rate, period of support and period of non-support.

TREADMILL AS A TRAINING AND SIMULATOR INSTRUMENT

Kollias et al. (1967) reported a study they had undertaken to determine the effectiveness of supplemental treadmill training. The hypothesis by Kollias et al. [1967:148] was "that a sense of running pace and rhythm gained on the treadmill might be transferred to running an outdoor course." The results were inconclusive and Kollias et al. felt that further work would have to be performed in order to make a more definite statement. It was interesting to note that the authors mention that Roger Bannister was thought to have run the four minute mile on the treadmill to assure himself that he could run it outdoors

Dal Monte et al. (1973) carried out a study to ascer-

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*The 'amplitude of movement' is the difference between maximum flexion and extension in degrees.

tain whether the motor-driven treadmill simulates middle and long distance running under the double aspect of energy cost and form of movement. The speeds chosen for running were 15, 18, and 20 Km/h which converts to 9.3, 11.2 and 12.4 mph respectively. The authors [1973:363] reported that "the difference between the two types of running tends to diminish with the increase of speed during the stride." The differences found by Dal Monte et al.,were that the extension phase and stride were shorter on the treadmill than on the track. However, Dal Monte et al. concluded:

> . . . that the treadmill may be considered, although within certain limits, a specific simulator of middle-distance running, as there is no outstanding difference kinematic or energy cost, from the track running as long as it is adopted at a speed close to that of competitions.

Dal Monte et al. further states that:

> The instrument can be used for training, for it allows control of proper breathing mechanics through the recording of lung ventilation and of pneumotachograms, heart frequency ECG and oxygen consumption, which can only be measured in a laboratory and not on the track.

COMPARISON OF TREADMILL AND OVERGROUND RUNNING

In 1971, Brookes et al. undertook the task of trying to find the degree of relationship between running on a track and running on a treadmill. The main concern of Brookes et al. was to examine the physiological differences encountered by runners who performed under both running conditions. The biomechanical analysis was limited to comparing the joint angles of the legs during one complete leg cycle. It was concluded

from the analysis of data that no major difference existed between the two conditions of running. Little attention seemed to be paid to the fact that similar end results can be achieved even though the methods used may differ greatly in nature.

Recently, Nelson *et al.* (1972) have published a study on the biomechanics of overground versus treadmill running. It was mentioned in the paper that three internationally recognized physiologists, Astrand, Balke, and Margaria had expressed, through personal conversation, the opinion that except for air resistance it can be assumed that there is no difference in running on the two types of surfaces. Nelson *et al.* attempted to examine the relationship between the two conditions of running by using cinematographic methods. Nelson *et al.* reported that treadmill running was characterized by longer periods of support, lower vertical velocity and less variable vertical and horizontal velocities than for overground running. As was the case with the study by Brookes *et al.*, the effects were analysed but only opinions could be offered as to what changes actually occurred in the runner's manner of propulsion.

ELECTROMYOGRAPHY AND ITS APPLICATION TO STUDIES OF HUMAN GAIT

The first electromyographical research which was relevant to a study on human gait was reported by Basmajian (1957). In this study, Basmajian takes issue with an earlier study by Markee *et al.* (1955). In direct opposition to the conclusion stated by Markee *et al.* Basmajian concludes that

the muscle belly of a human two-joint muscle acted as a unit whether the proximal or distal joint was being influenced. The implication being that a muscle which crosses two joints cannot act in isolation so as to affect only one of the joints.

Scherrer and Bourguignon (1959) carried out a study on the changes in the electromyogram resulting from fatigue. Scherrer and Bourguignon reported that the integrated sum of the E.M.G. recorded by surface electrodes increased in all work of average or increased power followed beyond a certain time. The global E.M.G. recorded under the same conditions showed an increased amplitude of the potentials and a decrease in their frequency.

In 1965, Bierman and Ralston reported that no detectable electromyographical potentials were observed in the rectus femoris or biceps femoris muscles during passive flexion and extention of the knee at rates up to 120 times per minute. Bierman and Ralston concluded that the classic stretch reflex does not occur in the normal human subject unless the muscle is stretched very rapidly as for example in the knee jerk. For active movement, Bierman and Ralston reported that the 'antagonist' produced a potential toward the end of the movement. The 'agonist' produced potentials which were of highest amplitude at the initiation of motion and then gradually diminished and ceased toward the end of the movement.

In 1966, Grossman and Weiner published a paper which dealt with some of the factors affecting the reliability of

surface electromyography. Analysis of data revealed that there was considerable doubt whether surface muscle action potentials (MAP) were simply a reflection of muscle tension. Grossman and Weiner warn the EMG researcher against trying to compare the relative state of contraction of one muscle against another. The problem is that a small increase of electrical activity in one muscle may represent a large part of its capacity for contraction, whereas in another muscle it may represent only a small portion.

Sutherland (1966) performed an electromyographical study of the plantar flexors of the ankle in walking. Sutherland found that the soleus muscle showed electrical activity when a vertical line drawn through the center of gravity fell behind the ankle joint. From this Sutherland concluded that the function of the soleus was to resist the kinetic force of forward movement rather than resist the force of gravity.

Kamon (1966) appears to be one of the first investigators to combine cinematography and electromyography for the purpose of analysing a skill. The synchronization was achieved by a means of a light which blinked on and off in the camera's field of view and was accompanied by simultaneous signal marks on the recording paper.

Broer and Houtz (1967) carried out a study to determine whether there are patterns of muscle function common to various complex sport skills. The author's found that there appeared to be basic patterns of muscular activity and that

the timing of activity for a given muscle was relatively constant for a group of similar skills. Also they found that the magnitude of potentials varied with the effort required by the muscle.

Komi and Buskirk (1970) reported a study conducted to determine the reproducibility of electromyographic measurements with fine-wire and surface electrodes. The authors found that the reproducibility of EMG recordings with surface electrodes was much better than with inserted wire electrodes. This would be expected since fine-wire electrodes are much more selective in muscle action potential measurement. Komi and Buskirk further state that their results suggest that the surface electrode technique can be utilized reliably in long term studies where EMG recordings are repeated at intervals up to several days.

Kamon (1971) reported on an electromyographical study which was carried out on jumping performance. Kamon stated (1971:157) that:

> The sequence of muscle activity and precise timing of interactions indicated that jumping, like any other movements of the leg and foot, is executed under reflex responses and with the whole movement regulated at subcortical levels without awareness of changes in the joints.

This statement resulted from Kamon's observation that complete muscle relaxation sometimes occurred during the flight, followed by the reappearance of action potentials at the end of the flight in anticipation of the landing.

Miyashita et al. (1971) investigated the relationship between electrical activity in muscle and speed of walking and running. Subjects used in the study performed on a motor driven treadmill at various speeds. Miyashita et al. reported from the study that the electrical activity increased according to the rate of leg movement.

Lewillie (1971) reported on an electromyographical study carried out with the use of telemetry on swimmers. The author found the electromyograms showed with sufficient accuracy the difference in activity of a specific muscle with the varying styles of swimming. Lewillie also found that the speed at which a subject swam was reflected in the EMG recordings.

Brandell et al. (1972) developed a method of obtaining EMG recordings from a subject who was either walking or running. The measurement system of Brandell et al. was dependent on a portable, six channel tape recorder which was carried on the subject's back. The obvious drawback of this type of recording apparatus is that the weight, which was given as seven pounds, will influence the runner's performance.

In an unpublished paper presented at the 1973 North American Regional meeting of the International Society of Electromyographic Kinesiology, Brandell reported two new findings from his study on treadmill and floor walking. Brandell found that the total gastrocnemius activity decreased

at the fast as compared to the moderate and slow speeds of walking. It seems that although the activity reached a higher degree of intensity, its duration was appreciably reduced at the faster speed. Brandell also reported that the gastrocnemius showed greater activity in treadmill, as compared to ground walking, at all speeds.

CHAPTER III

METHODS AND PROCEDURES

This study utilized the combined information gained through cinematography and electromyography to examine the muscular pattern, as well as the temporal and spatial relationship of a runner's legs during treadmill and overground running.

Electromyography was used to obtain a measure of the coordination sequence and muscular pattern of three leg muscles which were deemed major contributors to good running performance. The three major muscles which were examined and their action are listed in Table I.

TABLE I

EXAMINED LEG MUSCLES

Muscle	Action (Primary)
Biceps Femoris	Hip Extension Knee Flexion
Vastus Medialis	Knee Extension
Gastrocnemius	Knee Flexion Ankle Extension

Cinematography was used to compare the limb angle patterns for three speeds of running under the two specified conditions. Also, the pattern of the subject's total body center of gravity was examined for each of the running situations. The temporal pattern was also determined from cinematography.

APPARATUS

Electromyography (EMG)

In order to study the electromyographical pattern of a subject running overground and running on a treadmill, special EMG equipment was constructed. The equipment was designed so as not to hinder the runner's style of running, as well as be able to produce EMG signals which were relatively free from artifacts.

The most practical solution to the problems mentioned above, was to have the subject trail a single lightweight cable which led from the electrodes to a 'fixed' amplification and filtering system. For this purpose, 100 feet of Belden four-conductor shielded cable was used. However, in order to transport small electrical potentials, such as EMG signals, over a long cable, the cable itself had to be driven by a special ultra-low impedance circuit which was located on the runner. The weight of this remote transponder unit was approximately 0.5 pounds and was considered sufficiently light so as not to impede his motion.

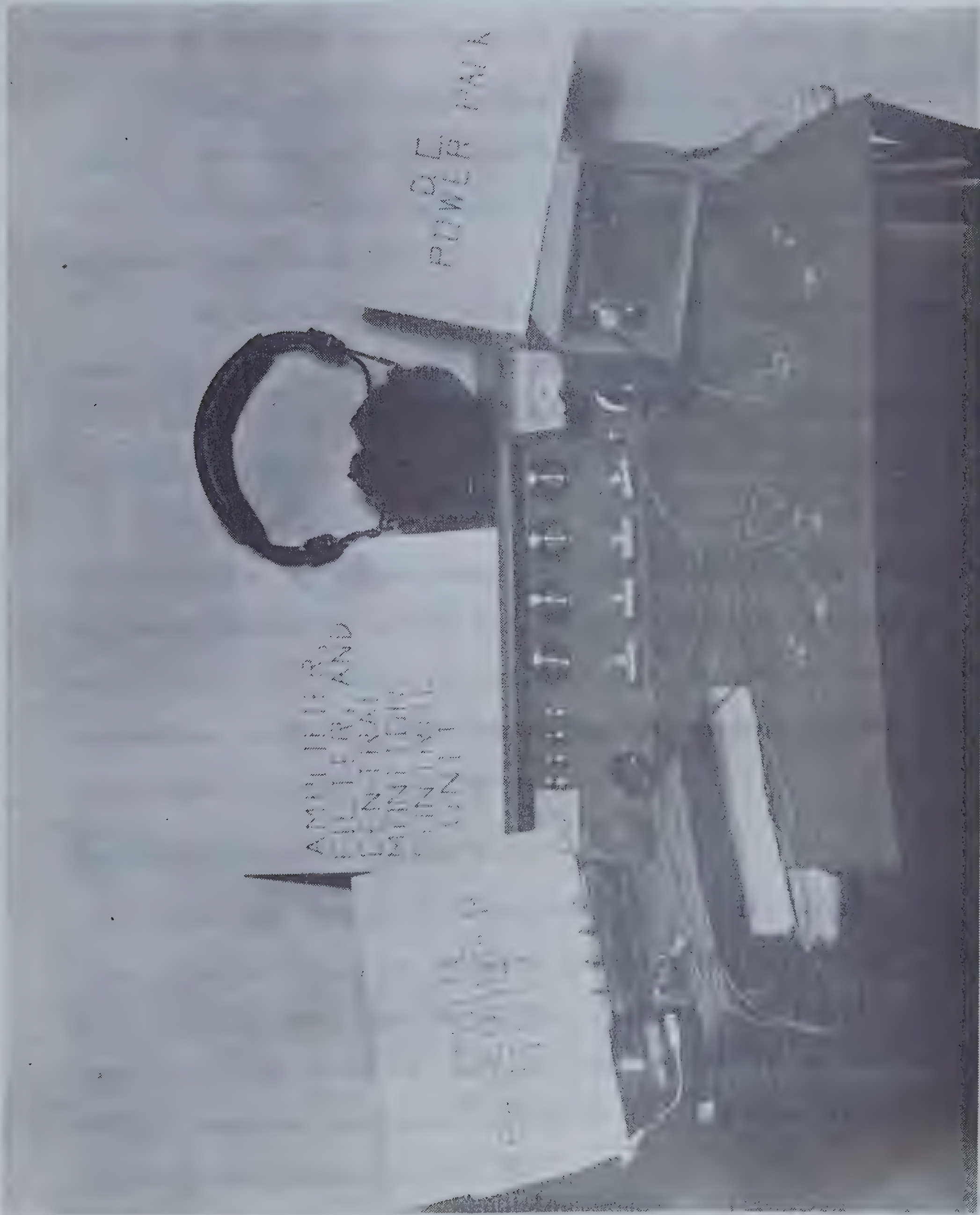


Figure 1. Electromyographical Apparatus

A more technically detailed description of the EMG apparatus used in this study is given in Appendix A.

Electrodes. The surface examination of the three muscles was done with bipolar surface electrodes. Stainless steel disc electrodes approximately two centimeters in diameter were used.

The two reference electrodes were attached to remote muscular regions (tibialis anterior, and adductor longus) so as to allow a more accurate measurement of the muscle action potentials generated from the muscles under examination.

The two electrodes, which were placed on each of the three muscles examined, were located such that one electrode was near the belly of the muscle and the other electrode near either its tendon of origin, or insertion. This procedure was used to lower the chance of cancelling MAP which was common to both electrodes.

Recording System

The raw EMG's were recorded on a four channel FM tape recorder (Hewlett Packard 3960 Series) at a tape speed of 3.75. At this tape speed the recorder was capable of recording from zero to 1250 Hz. The signal to noise ratio of the recorder was given as 48 DB and the tape speed accuracy was stated as $\pm$ 0.2%.

In order to determine whether artifacts were obscuring the data, the raw EMG signals were monitored on an

oscilloscope (Tektronix Type 502 Dual Beam) as well as headphones.

A permanent copy of the EMG tracings was produced on photographic paper (Kodak Linagraph 1930 paper) by using a continuous photographic recorder (Nihon Kohden Kogyo Co. Ltd.) which photographed the EMG output as it was played back into a dual beam oscilloscope.

In order to get some type of quantitative measurement of the EMG values, a sensitive 'area summator' was used. In this manner, the number of resets gave an indication of the electrical activity present in a muscle during a given time interval. A permanent record of the area summator tracing was also obtained by using the oscilloscope and continuous photographic recorder.

Camera

The camera used was a sixteen millimeter motion picture camera (Teledyne Camera Systems Millikan Model DBM 54). This particular camera was equipped with an interval timing light which left a light trace on the edge of the film at a rate of one every 0.1 seconds.

The exposed film and the timing or event mark were found to be separated by a set film distance of 14 frames. This precise distance was determined by counting the number of frames between the overexposed frame in the gate when the camera was not up to speed and the corresponding cluster of

marks resulting from the continued timing light exposure on one area of the film.

The pulse from the interval timing light was simultaneously recorded on one of the channels of the FM tape recorder so as to provide an accurate means of synchronizing the film and EMG tracings.

Kodak Four-X Reversal black and white double perforated film was used. The filming speed was set at approximately 70 fps.

Motion Analyser

A Triad Corporation film analyser (model V/R-100) was used for the film analysis.

Pacing Device

The pacing device consisted of a string on a motor driven pulley system. A small section of the green string was coloured white to act as a reference point for the runner to follow. The pulley's speed was governed by a variable transformer which was connected to the motor. The speed of the reference point was calculated by measuring the total length of string and the time the reference point took to make one complete revolution.

Subject

The subject was a skilled male runner who had been familiarized with the task over a period of three training

sessions. The subject was in execellent muscular condition for running performance so as to avoid any EMG changes which might possibly be attributed to fatique. The subject was 32 years of age and weighed 170 pounds.

TESTING PROCEDURES

The following experimental work was conducted at the University of Alberta Physical Education Building. A large gymnasium was used to test the 'overground' style of running while a motor driven treadmill situated in a laboratory was used to test the treadmill style of running. Testing indoors controlled the environmental variables of weather and light, as well as providing access to electrical power outlets. It also assured the experimenter that the subject was running on a horizontal surface for both the overground and treadmill performances.

The subject was dressed only in 'gym' shorts and running shoes. This facilitated the location of anatomical 'landmarks' when the subject's running style was analysed on film later.

The surface landmarks associated with the joint centers of the subject's wrist, elbow, shoulders, hip, knees, and ankles were located according to Williams and Lissner (1962:133), and marked with white adhesive tape on the skin surface.

The subject's skin at the point of electrode attachment was shaved. It was then thoroughly cleansed with

ethanol, and rubbed lightly with sandpaper to remove the horny surface of epidermis. The electrode cup was then filled with Sanborn Redux Electrode Paste and fastened to the site by means of Hewlett Packard two-sided electrode stickers.

The purpose of the above procedure was to lower the electrical impedance of the skin to a value which was negligible when compared to the high input impedance of the preamplifier. In addition to this precaution, the pre-amplifier was designed with a special common mode balancing circuit for each electrode. This allowed the operator to compensate for differences in skin-contact resistance, tissue impedance, and electrode impedance. It also minimized the usual effects of electrolytic action or contact potentials which develop at the electrode skin interface.

Since the subject was performing rapid and strenuous movements, adequate precaution had to be taken to ensure that electrode slippage did not occur. The problem was solved by using 'Pro-Wrap' (Bike Athletic Products Div., Kendall Co.), which is a light-weight, stretchy, foam rubber type material, to wrap around the leg and over the electrode.

All of the shielded wires which led from the electrodes on the subject were fastened down in such a manner so as to still permit freedom of movement of the leg. The lead wires were brought to one central location on the subject's back where the portable pre-amplifier pack was

situated. The positioning of the wires in this manner kept the wires from hindering the running movements of the subject.

Only the subject's left leg was wired for testing as it was the leg which could be easily photographed both on the treadmill and in the gymnasium.

In order to check whether the electrodes were placed over the desired muscle, the subject was asked to execute the primary action which the muscle normally performs. If there was a good EMG tracing, the electrode was assumed to be in place.

Each channel on the portable pre-amplifier was adjusted for minimum 'hum'. The gain on each of the channels of the 'fixed' amplifier was set so as to give a full scale EMG reading on the FM tape recorder. The 60 Hz notch filters built into the fixed amplifier were used.

The subject was first tested in the gymnasium. A 'resting level' EMG record was taken with the subject standing motionless in a relaxed manner.

The pacing device was set separately for 5, 8, and 11 mph. Eleven miles per hour was used as the upper limit since that was the upper limit of the treadmill's speed. The subject performed once for each of these set speeds. He ran for a distance of about 20 yards before he passed into the field of view of the camera. The timing pulse generator, which was used to synchronize the EMG recording and the film, was activated just after the camera and tape

recorder were turned on.

After the runner had performed at each of the set speeds, a range pole was filmed in the field of view so as to give a reference for assessing the actual distance that the subject moved per frame of film.

On the following day, testing was carried out on the treadmill. The subject was prepared as before with careful attention paid to the exact location of the electrodes. The amplification of the 'fixed' amplifier was set so as to give good full scale recordings.

Because of the location of the treadmill, a large 4' x 6' mirror had to be used in filming the subject. The mirror was arranged so that the left side of the runner was viewed. Special attention was paid to the alignment of the mirror in order to insure that the reflected light rays from the subject were those rays emitted perpendicular to the plane of running motion.

A 'resting level' EMG record was then made with the subject standing motionless beside the treadmill which was operating. The speed of the treadmill was then set at 11 mph and the subject performed at that speed. The timing pulse generator unit was activated after the camera and tape recorder had been turned on.

The subject was then recorded at 10, 9, 8, 7, 6, 5, and 4 mph so as to allow for the chance of error in the 'set' speed that the runner performed in the gymnasium.

After the subject had completed his running performances, the range pole was filmed in the field of view so as to give a reference for assessing the actual distance that the subject moved per frame of film.

ANALYSIS

As was mentioned earlier in this chapter, a permanent record of the EMG signals was obtained by using a continuous photographic recorder which photographed the tape playback on an oscilloscope. The filming speed of the continuous photographic recorder was set at 10 cm/sec.

The timing pulse marker was shown on the 'area summation' trace by feeding the timing pulse into the inverting end, and the area summation signal into the non-inverting end, of one of the channels of the oscilloscope. That channel was then set on differential mode.

The area summator's electrical base line level was zeroed separately for all three muscles using the resting EMG level that each muscle had produced on the day of testing.

The exact link-up of the runner's movements and EMG pattern was obtained by counting from the start of each trial the same number of pulse marks on the EMG tracing and on the film. It was then taken into account that the pulse marker preceded the actual frame of interest by a distance of 14 frames.

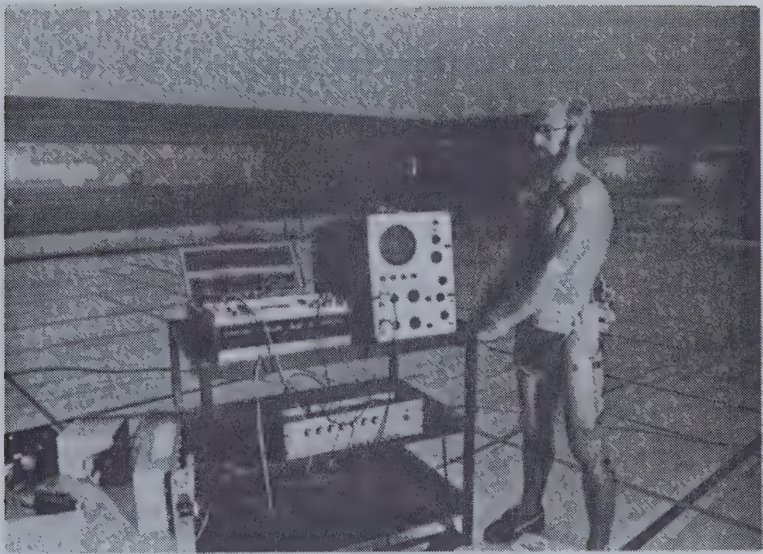


Figure 2. Subject and EMG Equipment.

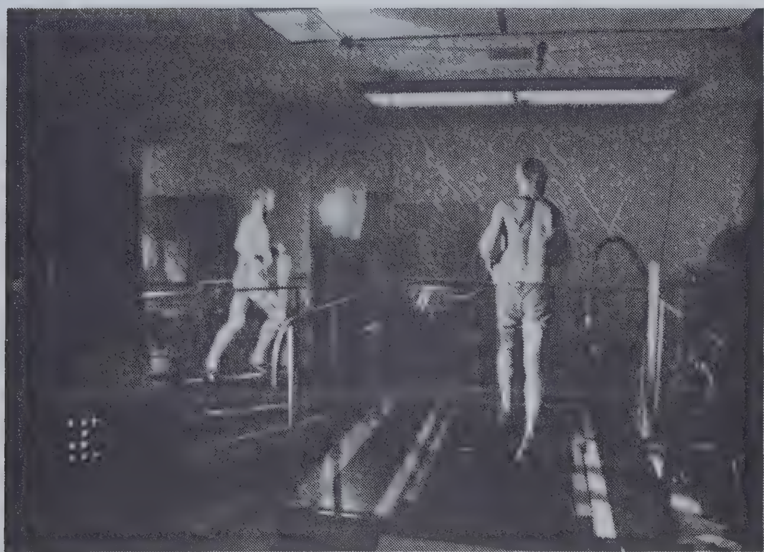


Figure 3. Subject performing on the Treadmill.

The vertical and horizontal displacement of the total body's center of gravity was calculated with the aid of a computer program which utilized the 'principle of moments' in its determination of the position of the center of gravity. Dempster's data, as cited by Williams and Lissner (1962:132), on relative masses of the segments and segmental center of gravity locations was used in this program.

In order to calculate ankle, knee, and hip angles of the left leg of the subject during the various stages of running performance, a computer program which utilized the 'cosine law' was developed (See Appendix B).

A computer program was then written for the 'Calcomp' plotting device which was used to draw graphs of leg angles against frame number, as well as center of gravity position against frame number.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS

The film was first analysed to determine the actual running speed of the subject in the gymnasium (see Appendix C). It was found that the three speeds, which would have to be analysed on the treadmill, were 5, 9, and 11 mph.

Temporal Relationship Between Treadmill and Overground Running

The length of time that the subject spent in each of the six phases of a running stride was determined from cinematographical analysis. As well as this, the total time that the subject was in contact with the ground, and the total time that he was free in the air, was calculated (Table II). A percent comparison was also made of the time spent in contact with the running surface, and the time spent in the air.

Spatial Relationship Between Treadmill and Overground Running

The vertical fluctuation of the subject's center of gravity was analysed and plotted against frame number (see Fig. 4 and Fig. 5). The numerical results may be found in Table III. The values listed in the table are the differences

TABLE II

TEMPORAL RELATIONSHIP BETWEEN TREADMILL (TM) AND OVERGROUND (OG) RUNNING

RUNNING CLASSIFICATION	FORWARD SWING		FOOT DESCENT		FOOT STRIKE		MID-SUPPORT		TAKE-OFF		FOLLOW THROUGH		TOTAL STRIDE TIME	TIME IN AIR	TIME CONTACTING RUNNING SURFACE (Both Legs)
	Frame Interval	Time (Sec)	Frame Interval	Time (Sec)	Frame Interval	Time (Sec)	Frame Interval	Time (Sec)	Frame Interval	Time (Sec)	Frame Interval	Time (Sec)			
5 mph OG	0>21	.30 36.1%	21>34	.19 22.9%	34>37	.04 4.8%	37>46	.13 15.7%	46>56	.14 16.9%	56>58	.03 3.6%	.83	.21 25.3%	.62 74.7%
5 mph TM	2>22	.30 38.0%	22>33	.16 20.3%	33>35	.03 3.8%	35>44	.15 19.0%	44>52	.12 15.2%	52>54	.03 3.8%	.79	.19 24.1%	.60 75.9%
9 mph OG	3>23	.29 39.2%	23>36	.19 25.7%	36>39	.04 5.4%	39>44	.07 9.5%	44>52	.12 16.2%	52>54	.03 4.0%	.74	.28 37.8%	.46 62.2%
9 mph TM	3>21	.27 39.1%	21>31	.15 21.7%	31>33	.03 4.3%	33>40	.11 15.9%	40>45	.08 11.6%	45>48	.05 7.2%	.69	.25 36.2%	.44 63.8%
11 mph OG	3>23	.29 40.3%	23>38	.21 29.2%	38>40	.04 5.6%	40>45	.06 8.3%	45>51	.09 12.5%	51>53	.03 4.2%	.72	.34 47.2%	.38 52.8%
11 mph TM	3>19	.24 40.7%	19>28	.14 23.7%	28>30	.03 5.1%	30>35	.07 11.9%	35>39	.06 10.2%	39>42	.05 8.5%	.59	.27 45.8%	.32 54.2%

TABLE III

MAXIMUM VERTICAL FLUCTUATION OF TOTAL BODY C OF G

Running Classification	Maximum Vertical Fluctuation (ft.)
5 mph (O.G.)	0.43
5 mph (T.M.)	0.34
9 mph (O.G.)	0.35
9 mph (T.M.)	0.24
11 mph (O.G.)	0.34
11 mph (T.M.)	0.21

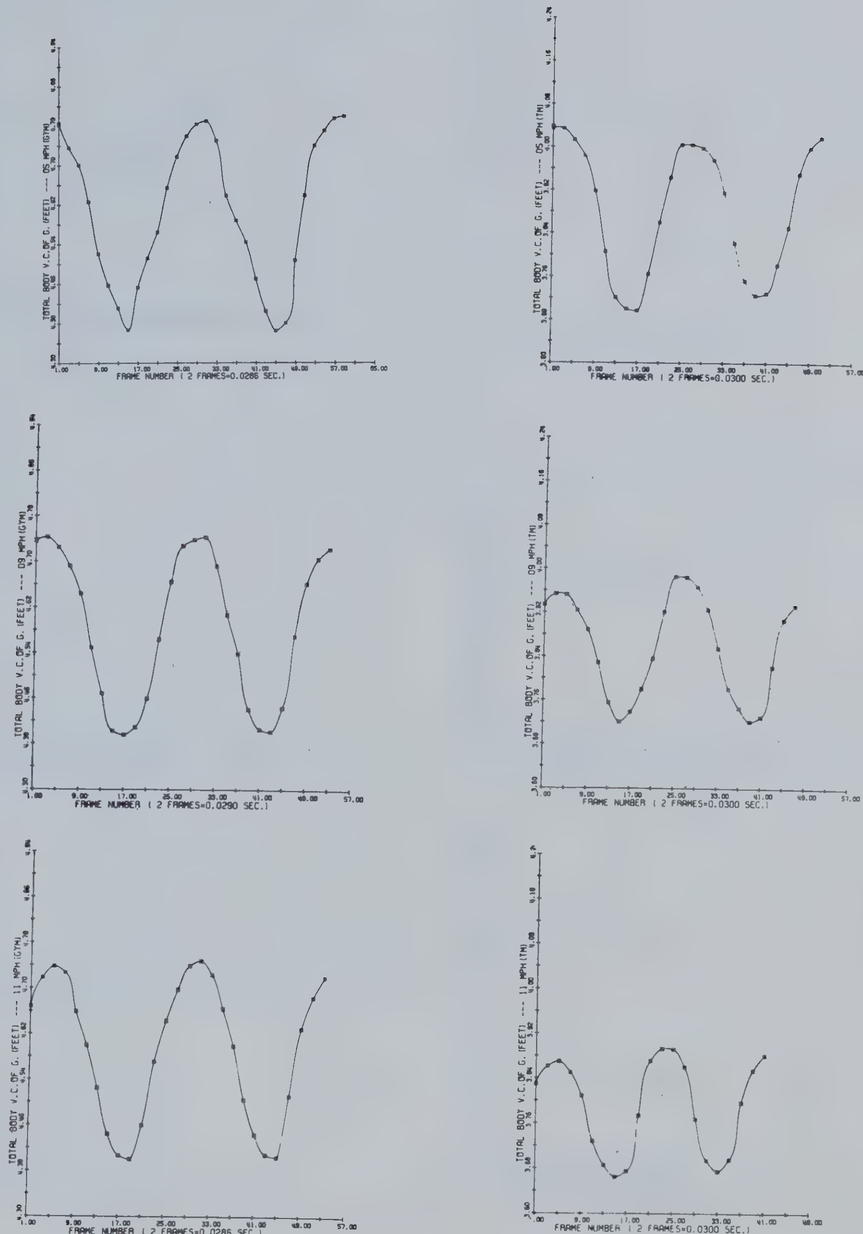


Figure 4. Vertical Displacement of C. of G. (Treadmill and Overground)

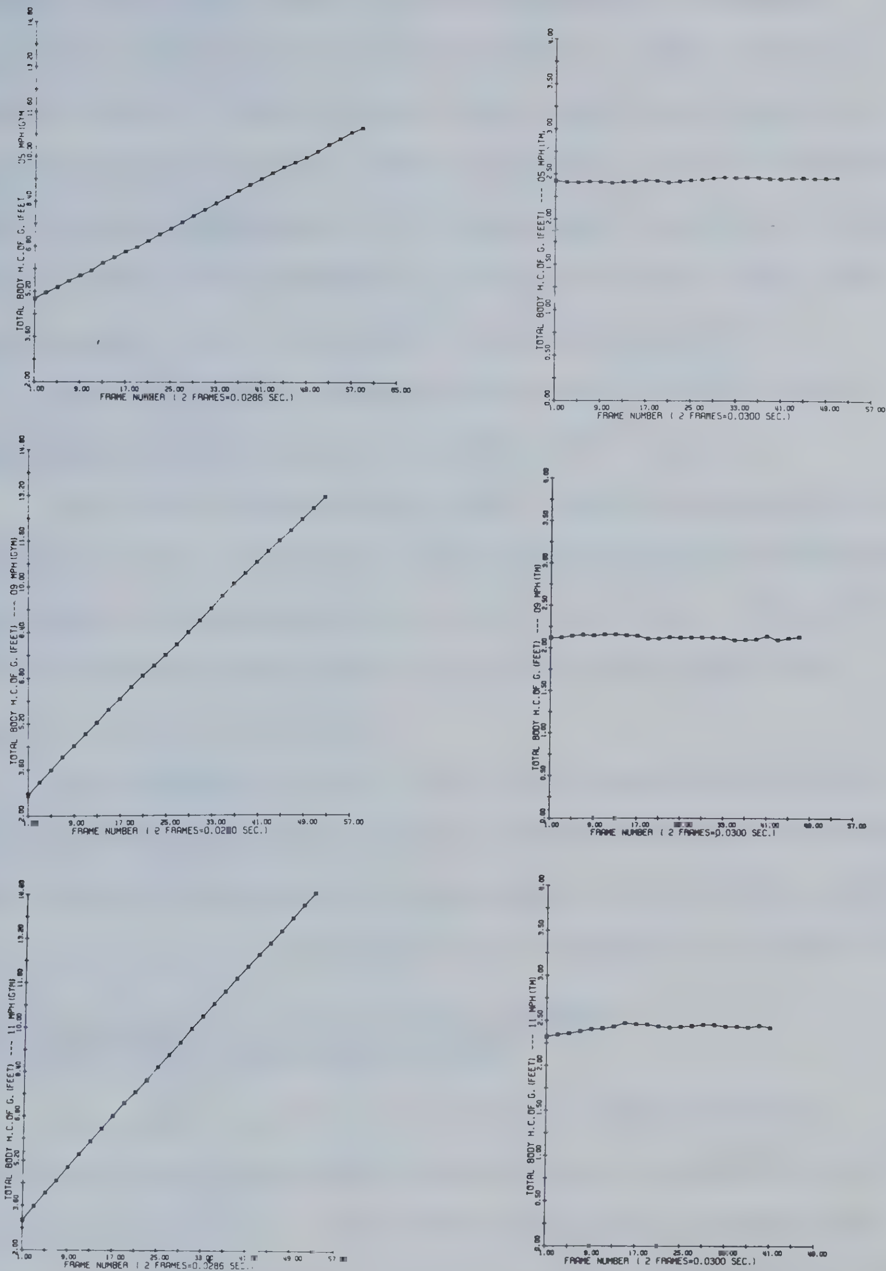


Figure 5. Horizontal Displacement of C. of G. (Treadmill and Overground)

between the maximum and minimum amplitude of movement. It should be noted that the actual ordinate scale, shown in Figures 4 and 5, does not have the running surface as its zero point of reference. The zero point used for overground running was approximately 1.5 feet below the actual running surface level. For treadmill running the zero point was approximately 0.76 feet below the running surface.

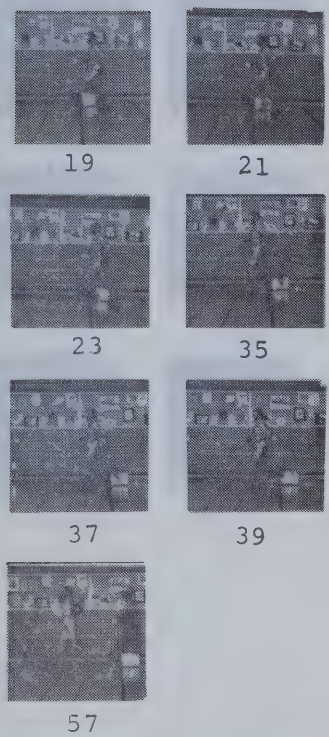
The horizontal fluctuations were of small enough magnitude as to not warrant further investigation.

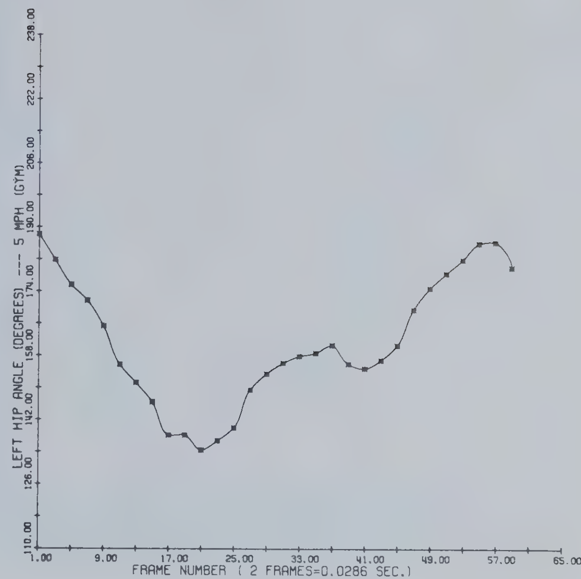
The joint angles of the left leg for an entire running stride were calculated for each different classification of running. Graphical plots of the hip, knee, and ankle angles against frame number (i.e. time) were made (see Figures 6 to 14 inclusive).

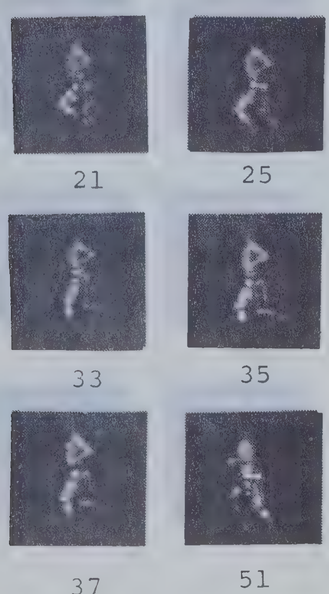
In addition to this, the individual hip, knee, and ankle angle curves were combined and plotted on one graph. This plotting procedure was performed for all three speeds under both running conditions (see Figures 15, 16, and 17).

Electromyographical Relationship Between Treadmill and Overground Running

The muscle action potentials of gastrocnemius, vastus medialis, and biceps femoris were recorded for the subject's left leg. These EMG signals were synchronized with each other as well as with the film (see Figures 18 to 23 inclusive).







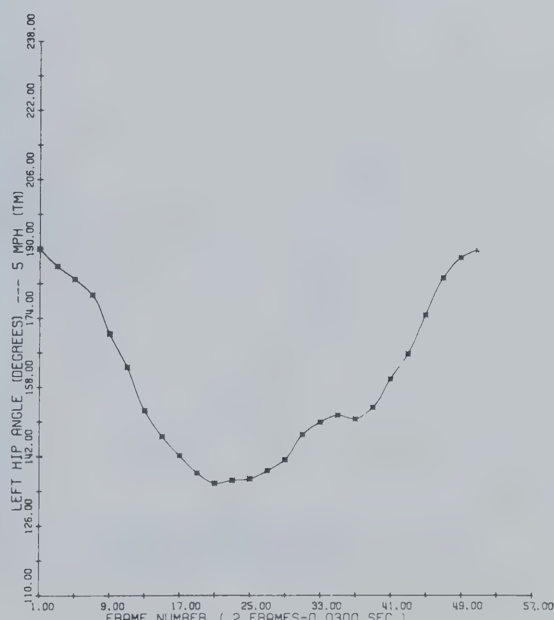


Figure 6. Hip Angle - 5 mph (T.M. and O.G.)

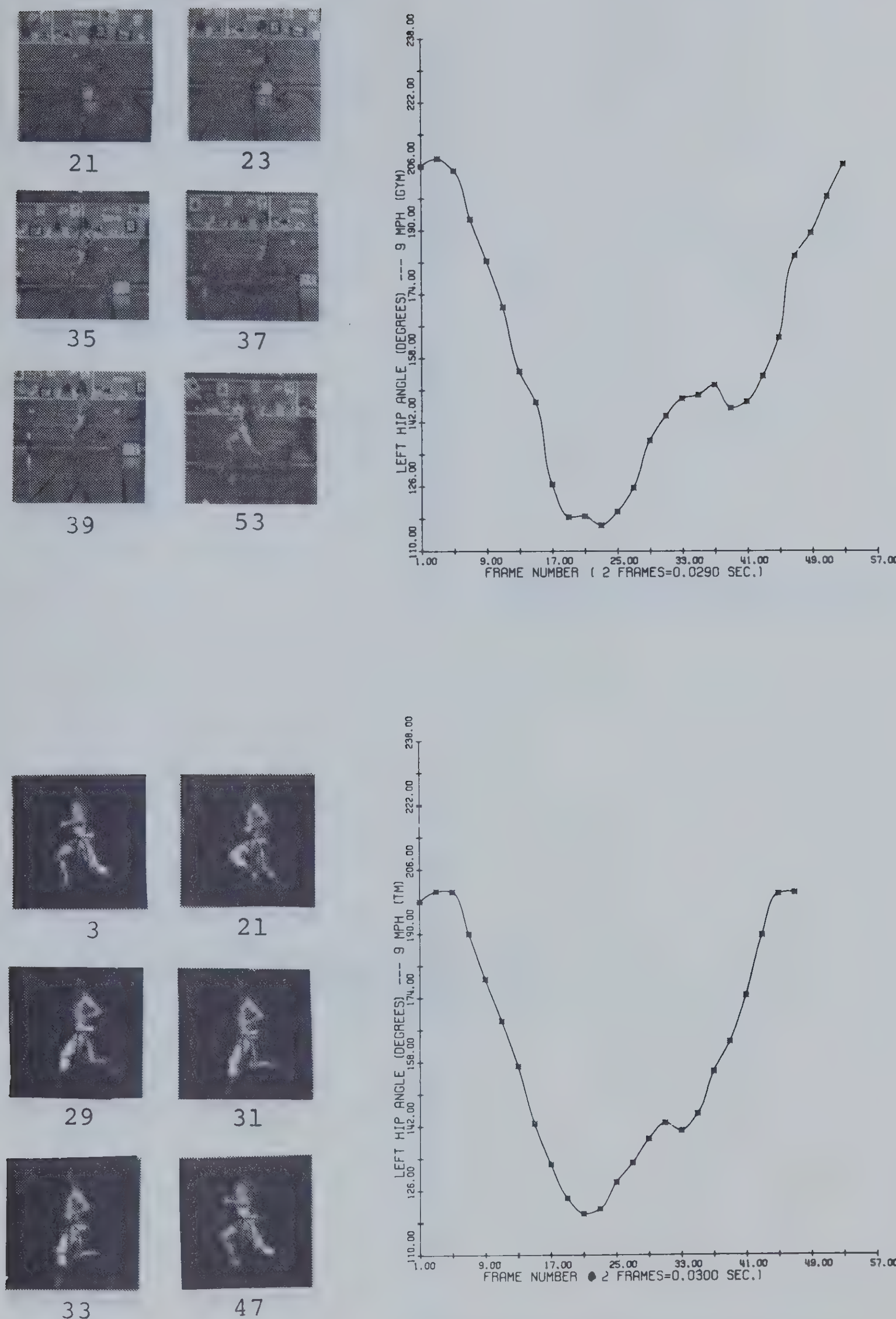
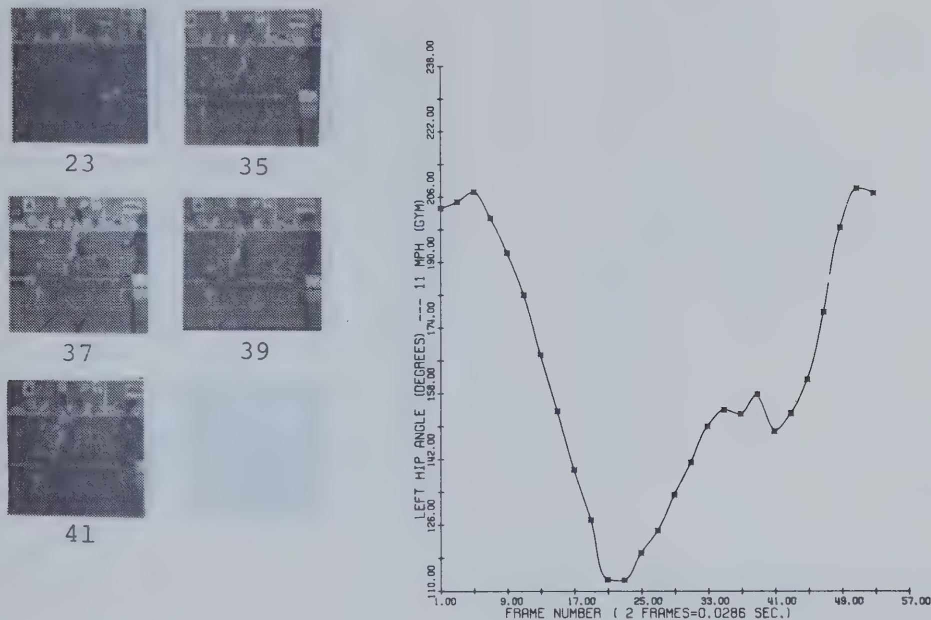


Figure 7. Hip Angle - 9 mph (T.M. and O.G.)



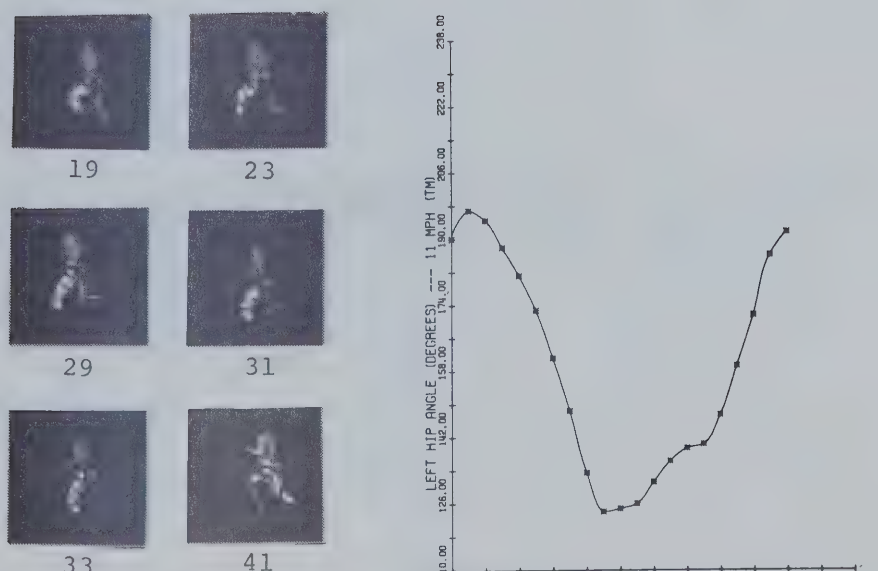


Figure 8. Hip Angle - 11 mph (T.M. and O.G.)

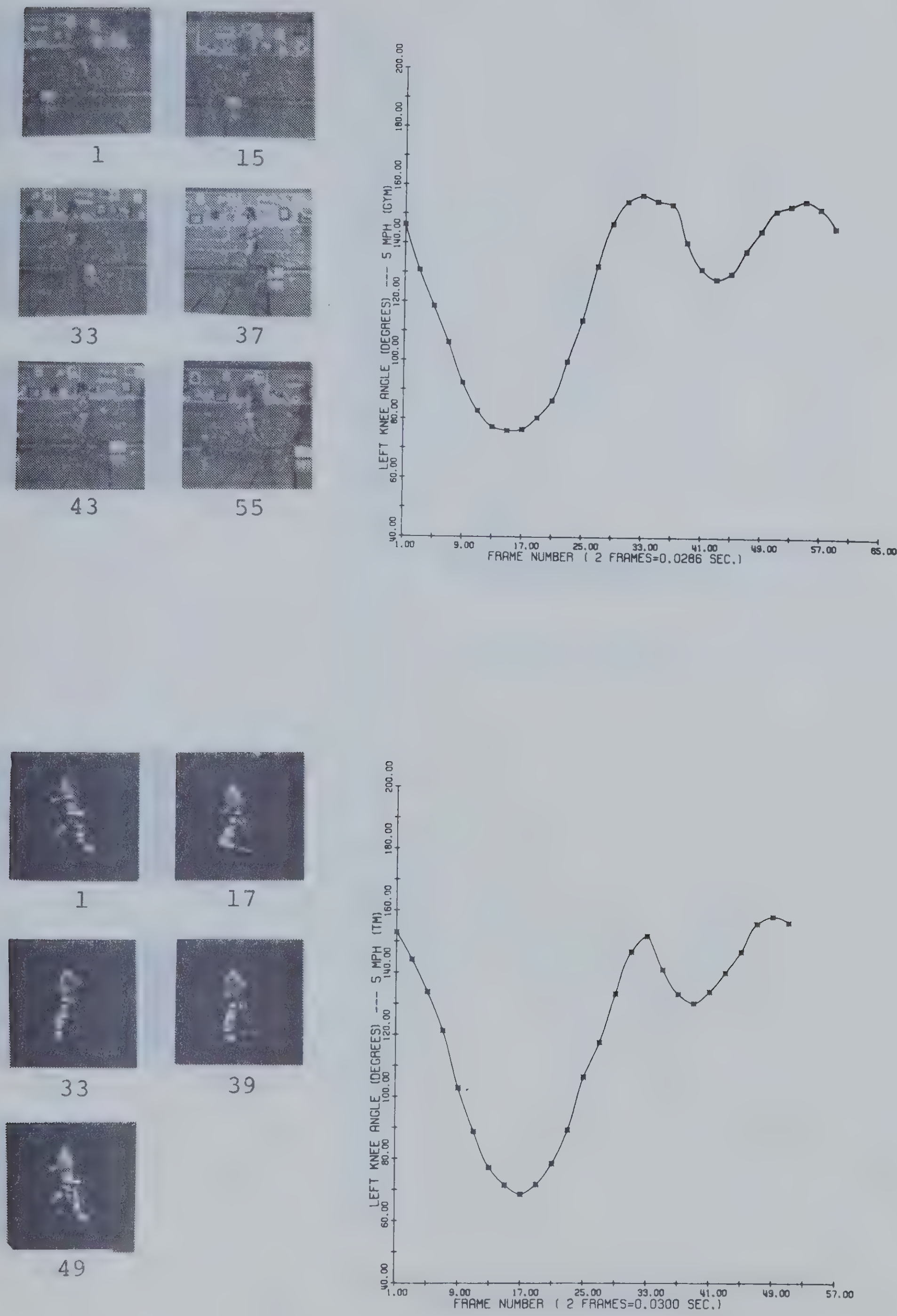


Figure 9. Knee Angle - 5 mph (T.M. and O.G.)

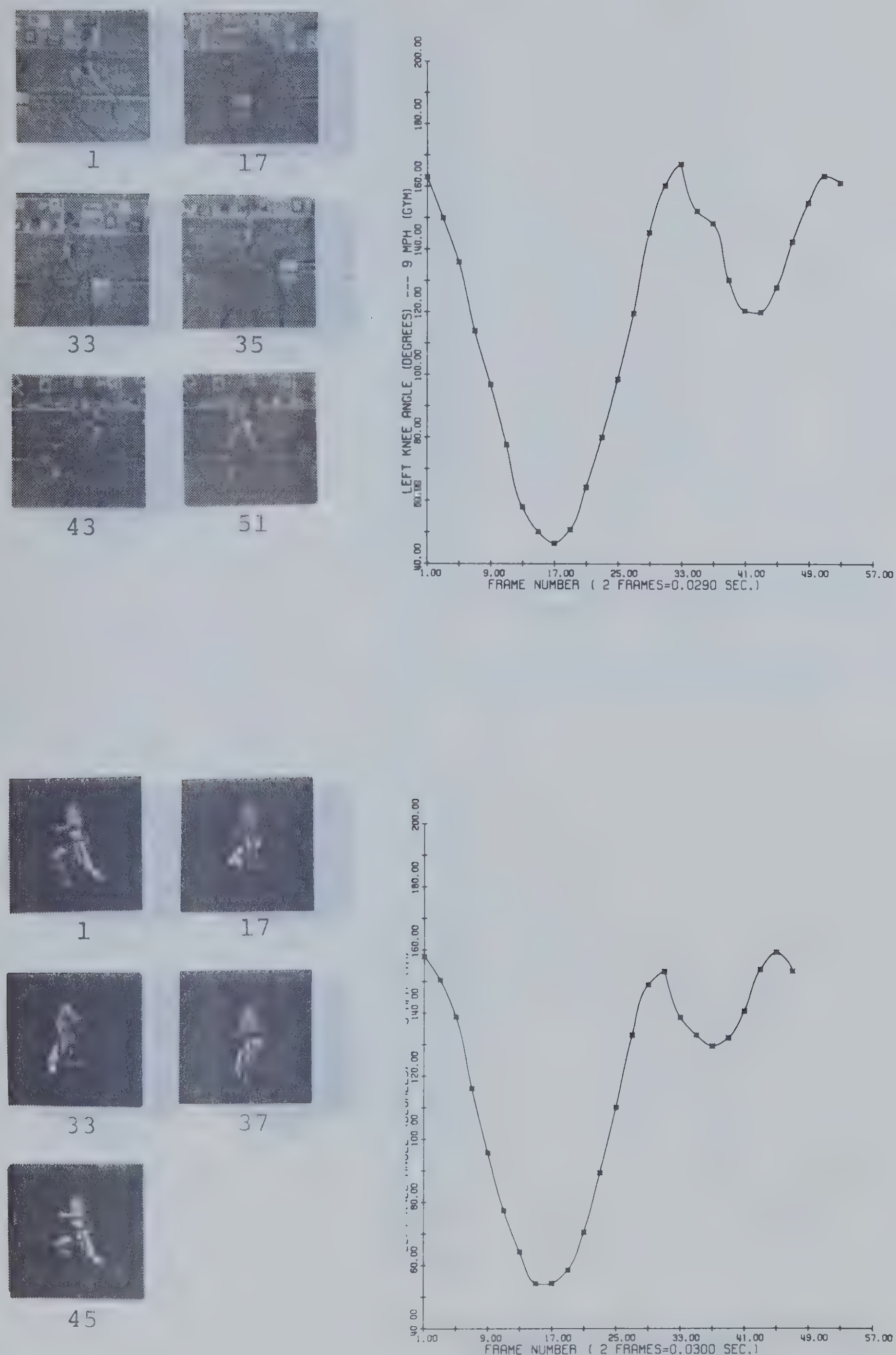
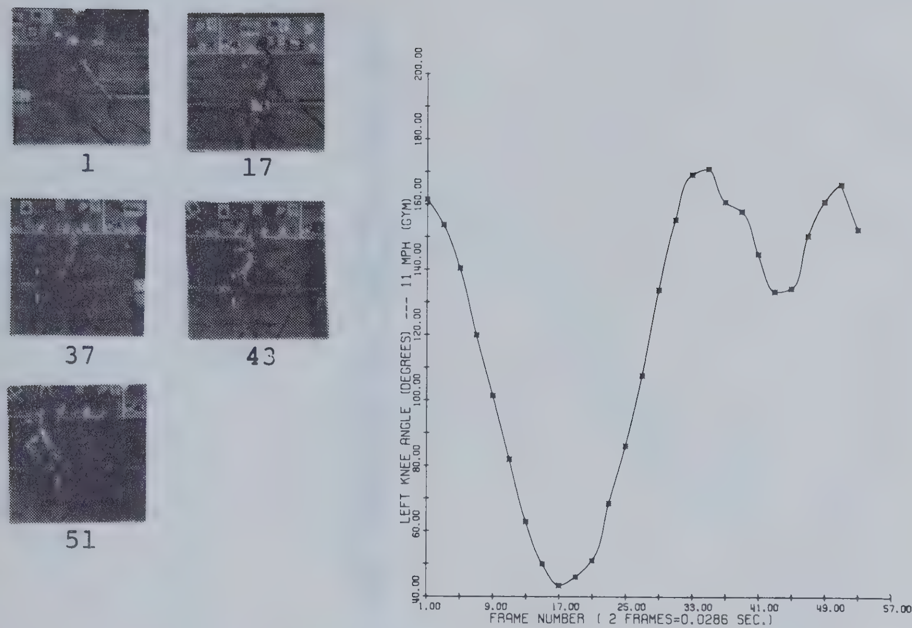


Figure 10. Knee Angle - 9 mph (T.M. and O.G.)



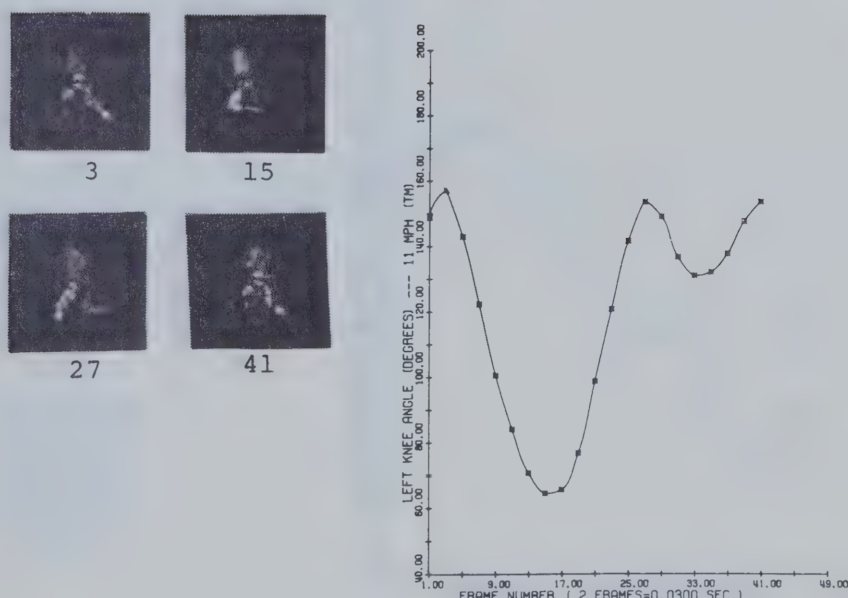


Figure 11. Knee Angle - 11 mph (T.M. and O.G.)

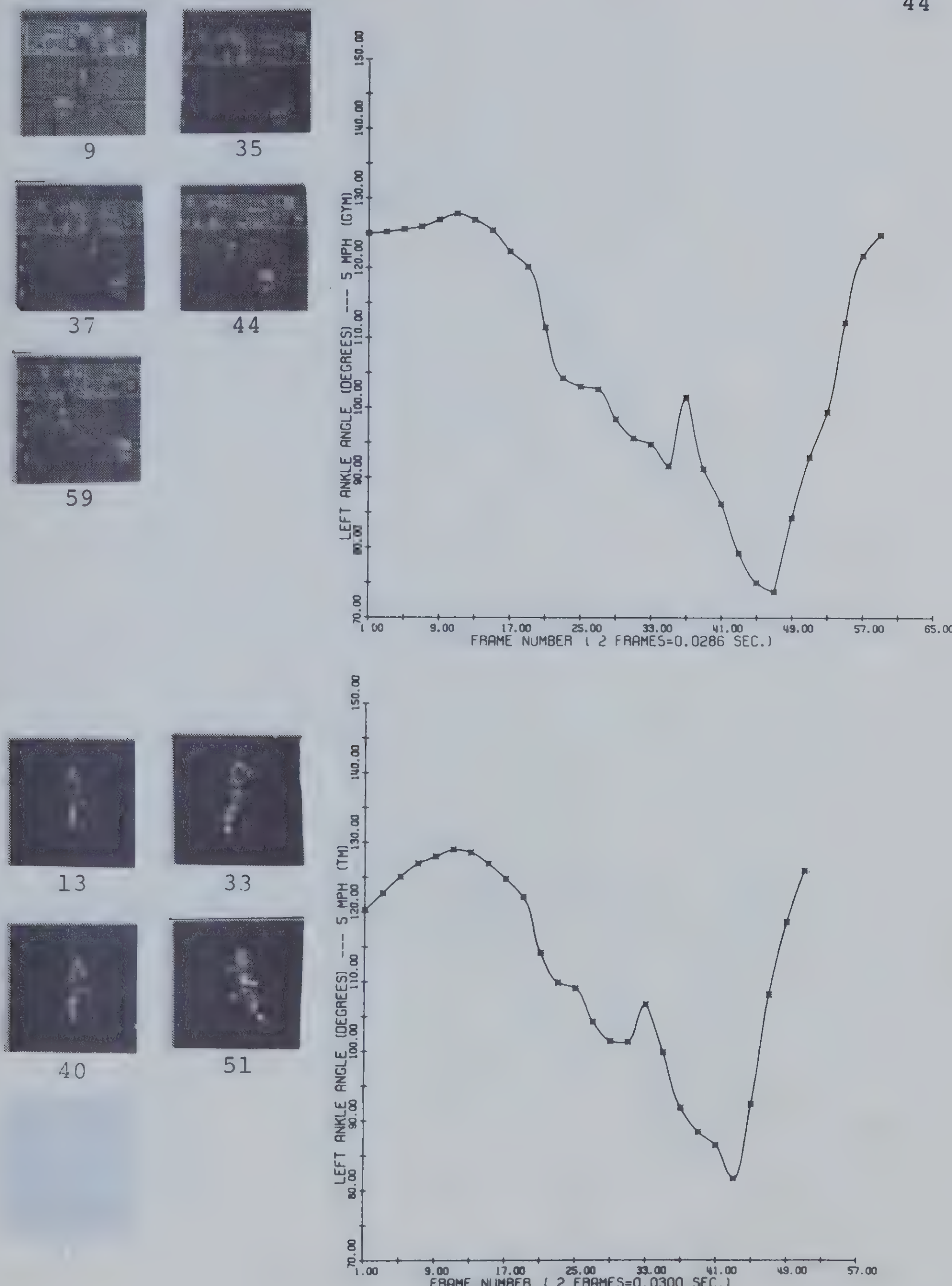


Figure. 12. Ankle Angle - 5 mph (T.M. and O.G.)

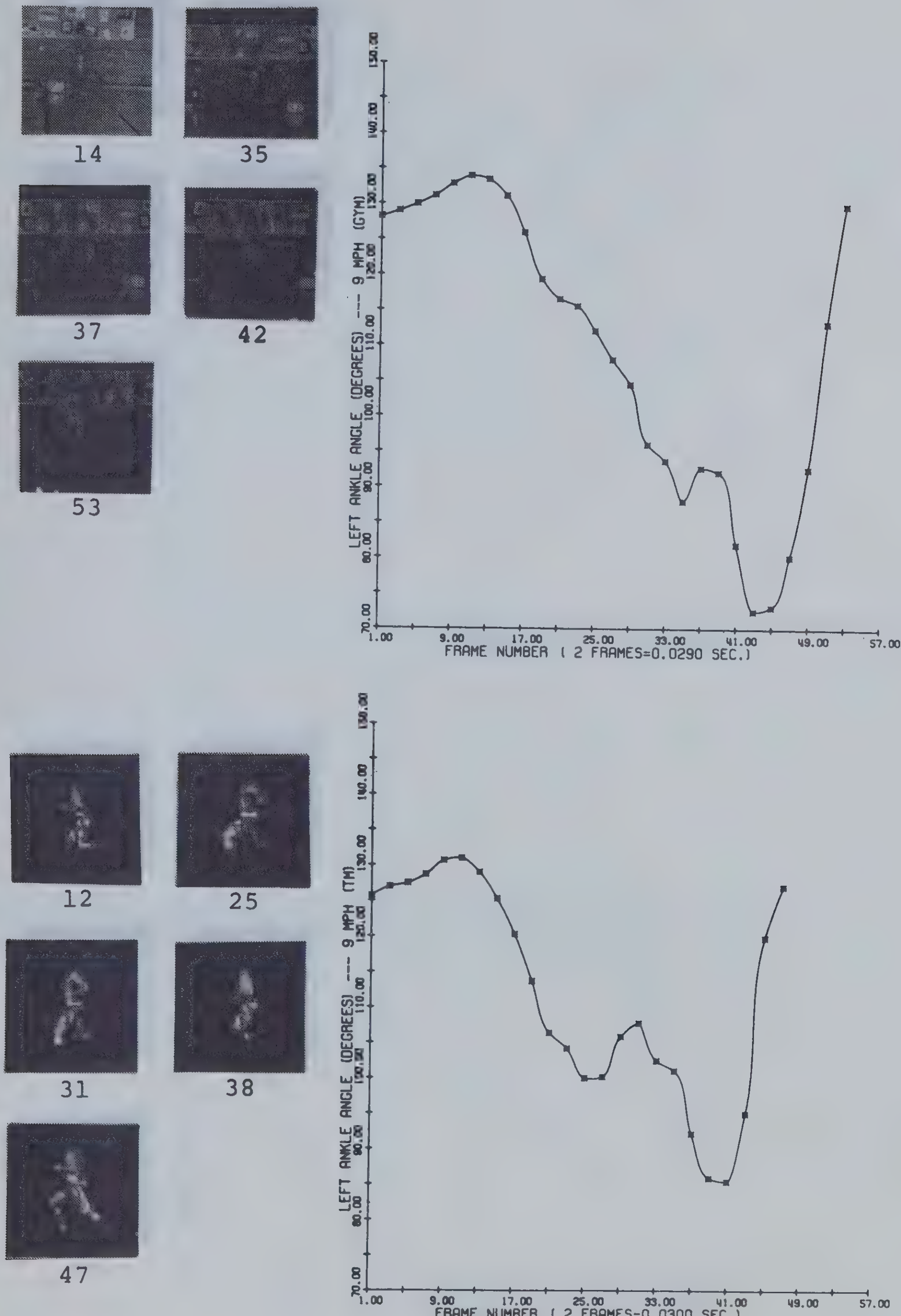
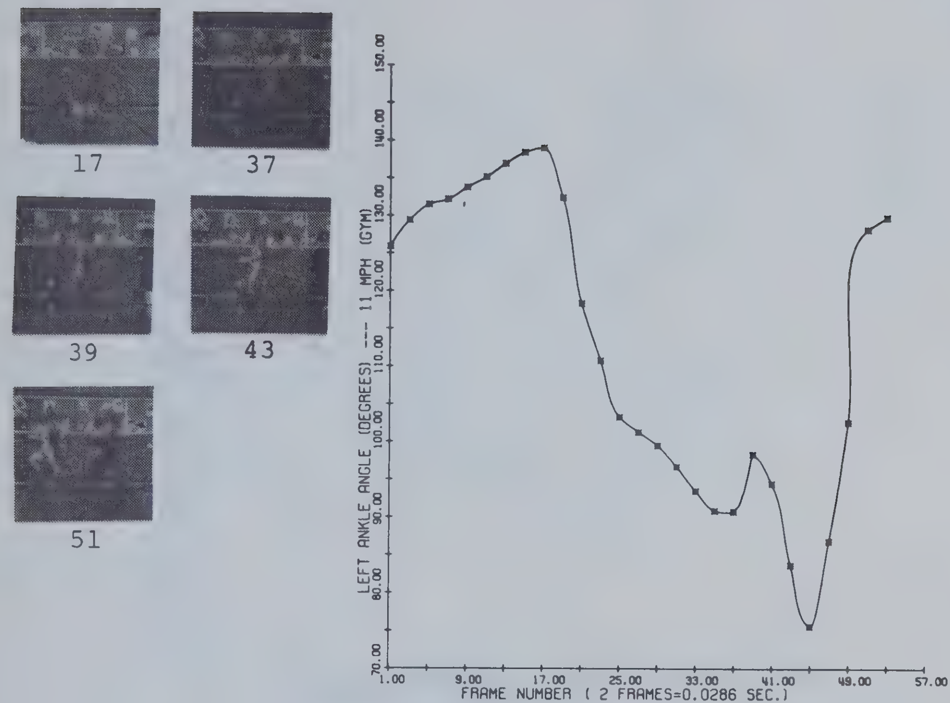


Figure 13. Ankle Angle - 9 mph (T.M. and O.G.



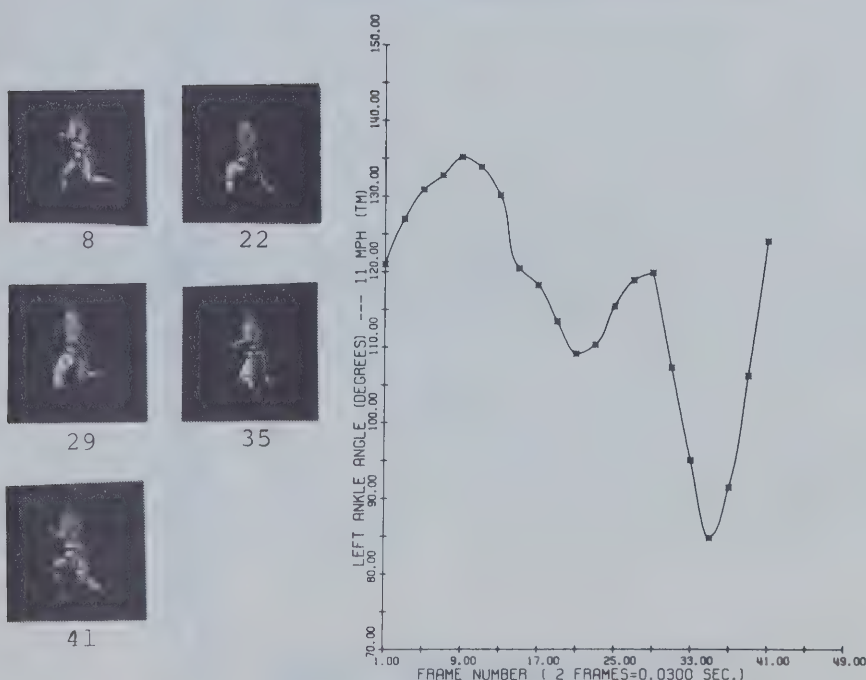
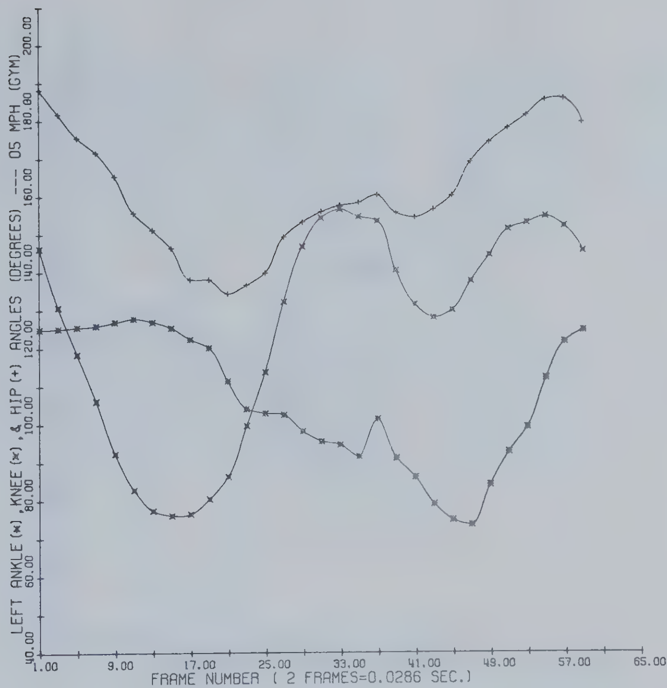


Figure 14. Ankle Angle - 11 mph (T.M. and O.G.)



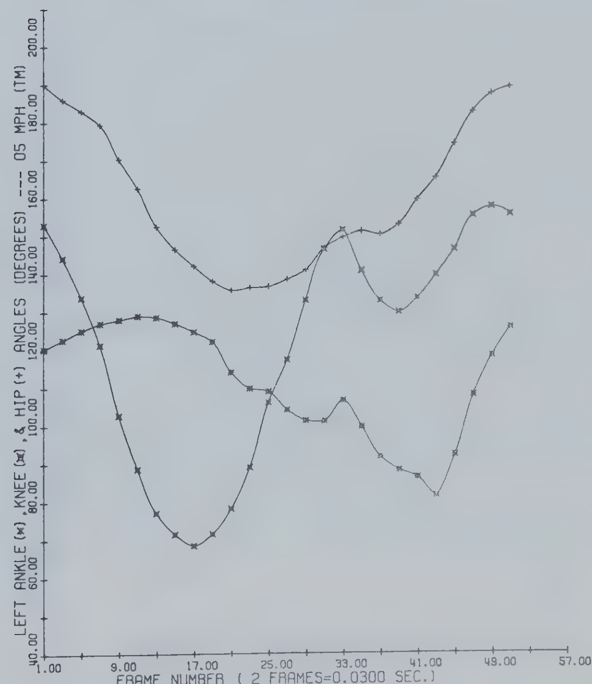


Figure 15. Ankle, Knee and Hip Angles - 5 mph (T.M. and O.G.)

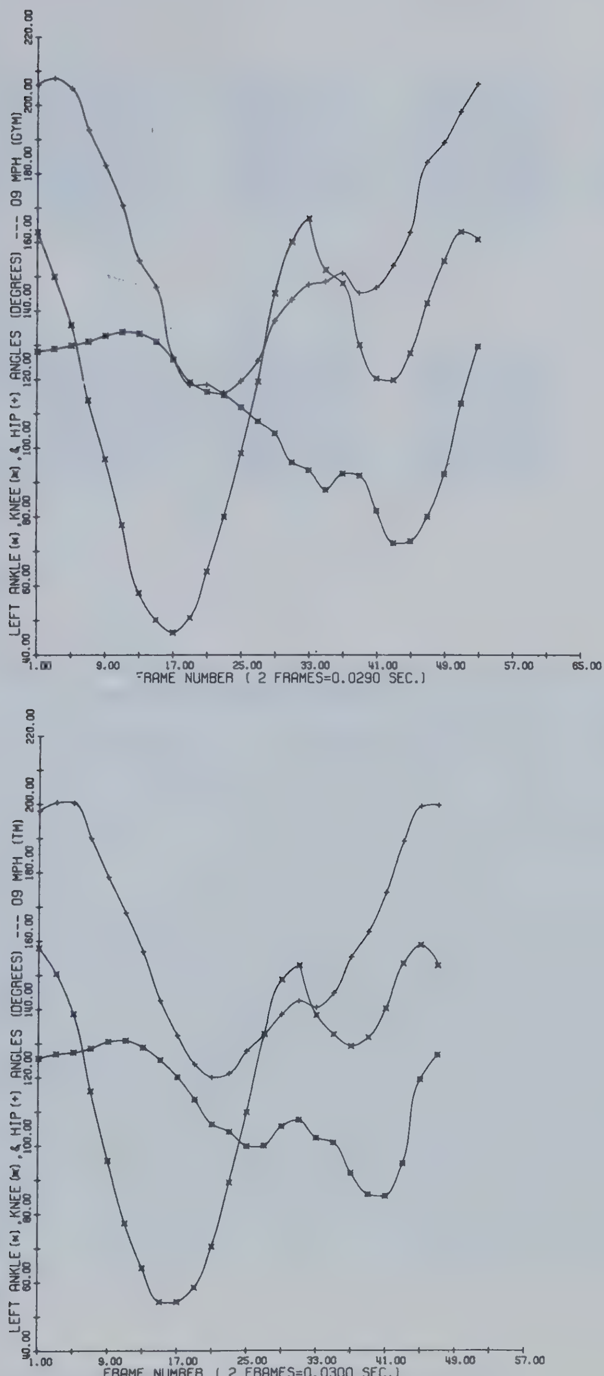
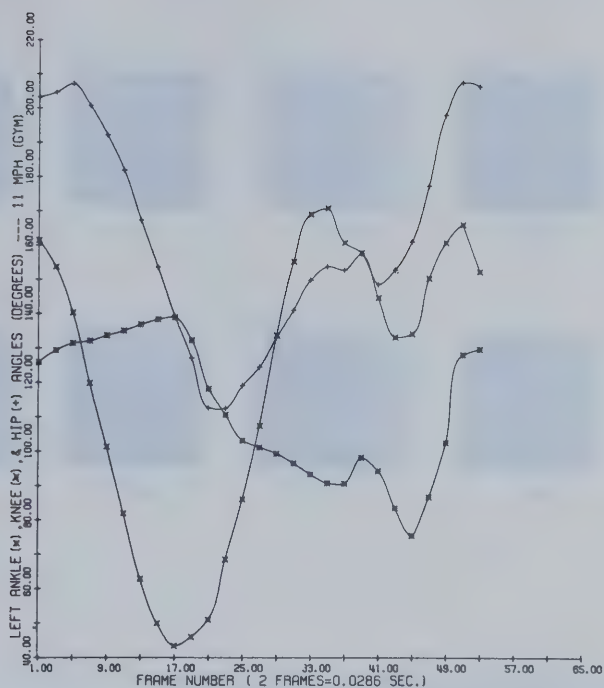


Figure 16. Ankle, Knee and Hip Angles - 9 mph (T.M. and O.G.)



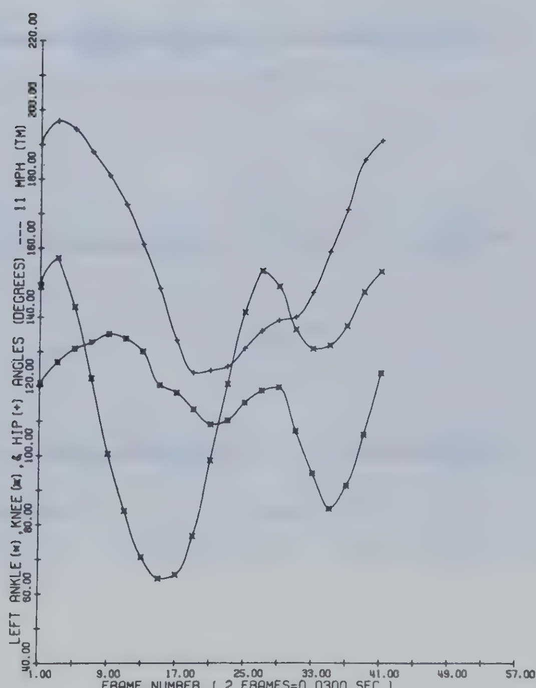


Figure 17. Ankle, Knee and Hip Angles - 11 mph (T.M. and O.G.)

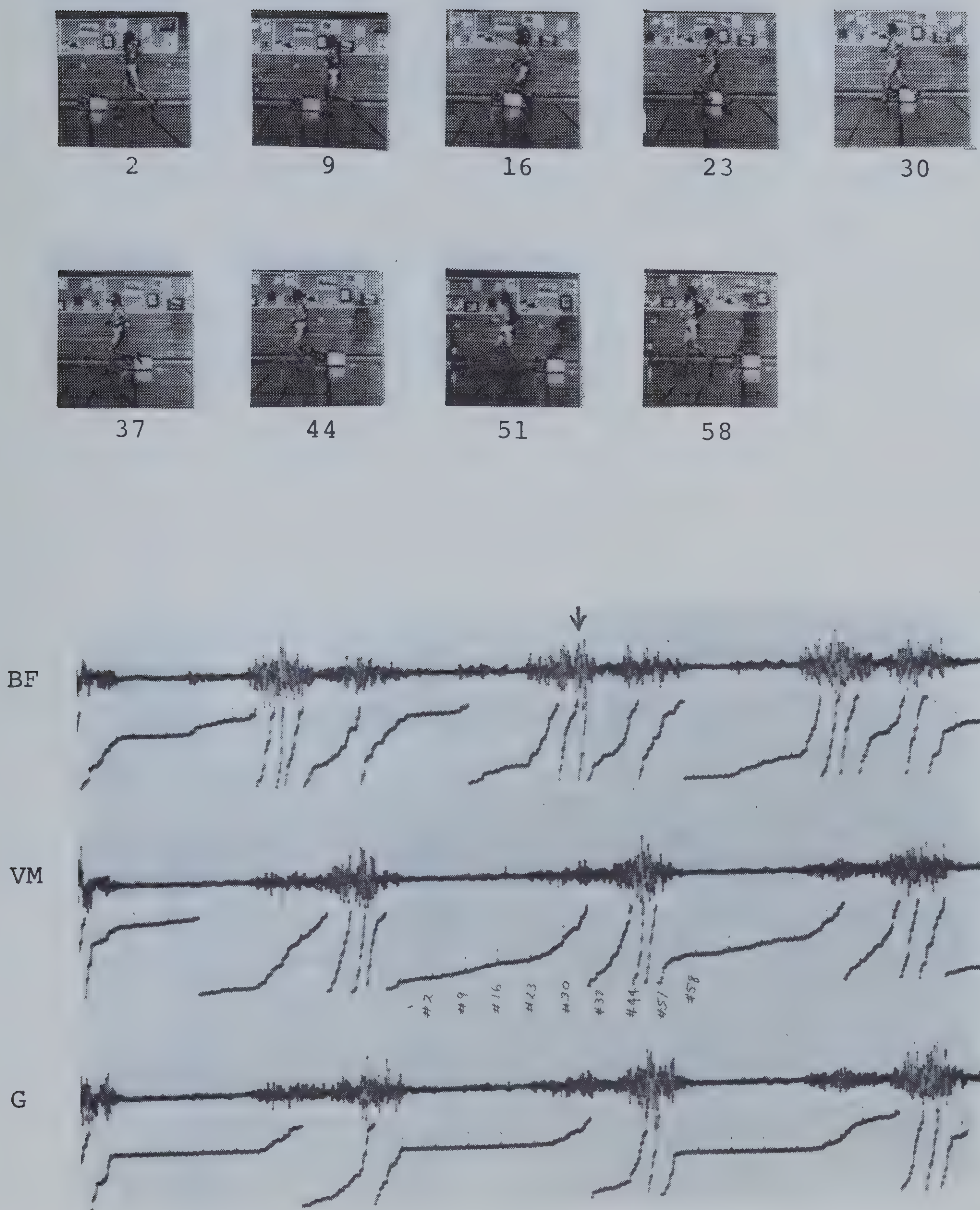


Figure 18. EMG and Area Summation; Biceps Femoris (BF), Vastus Medialis (VM), and Gastrocnemius (G) - 5 mph (O.G.)

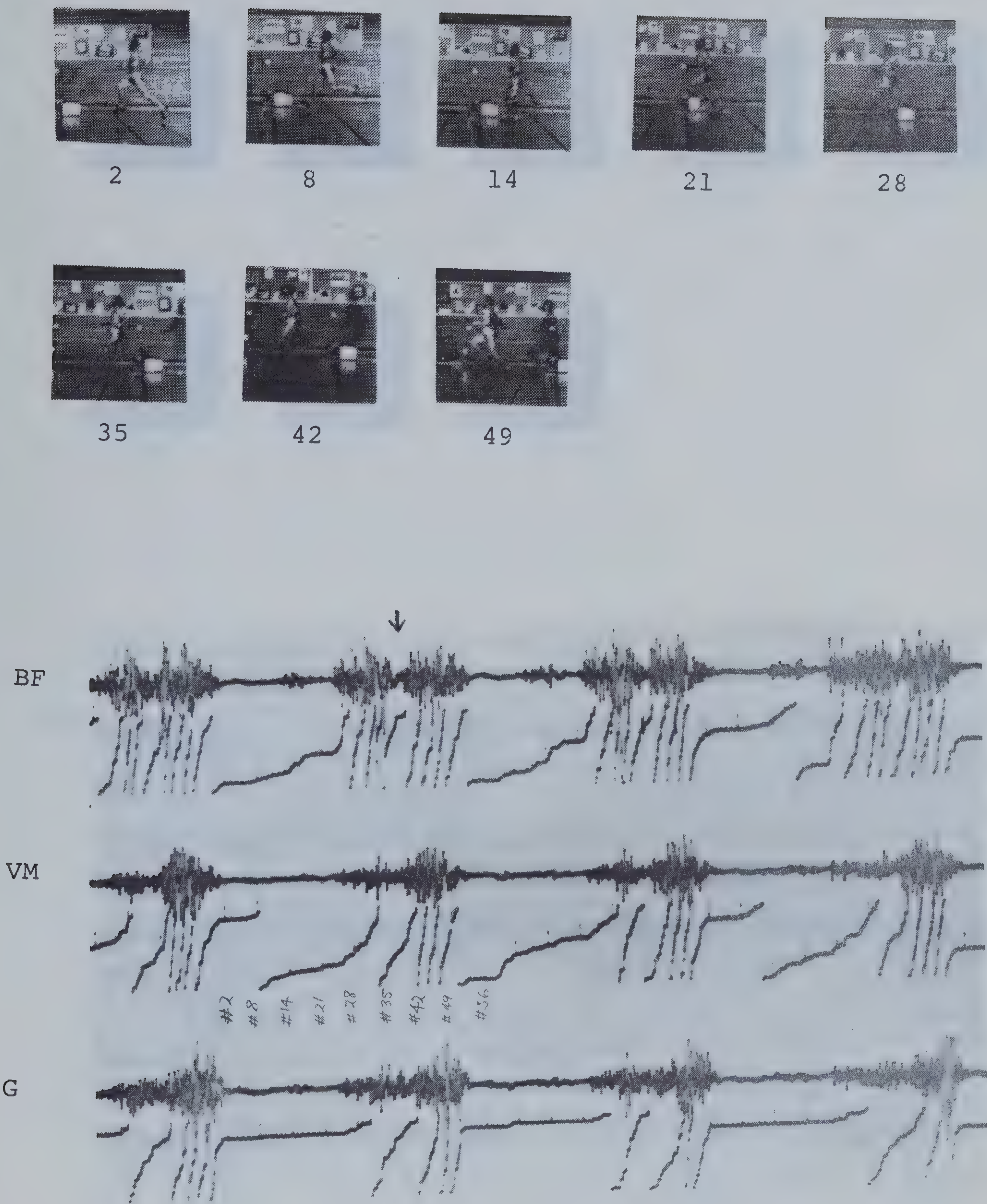
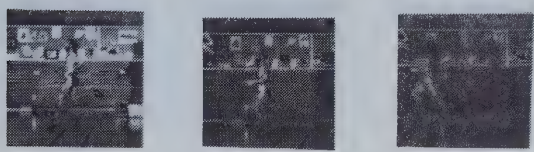


Figure 19. EMG and Area Summation - 9 mph (O.G.).

2 9 16 23 30



37 44 51

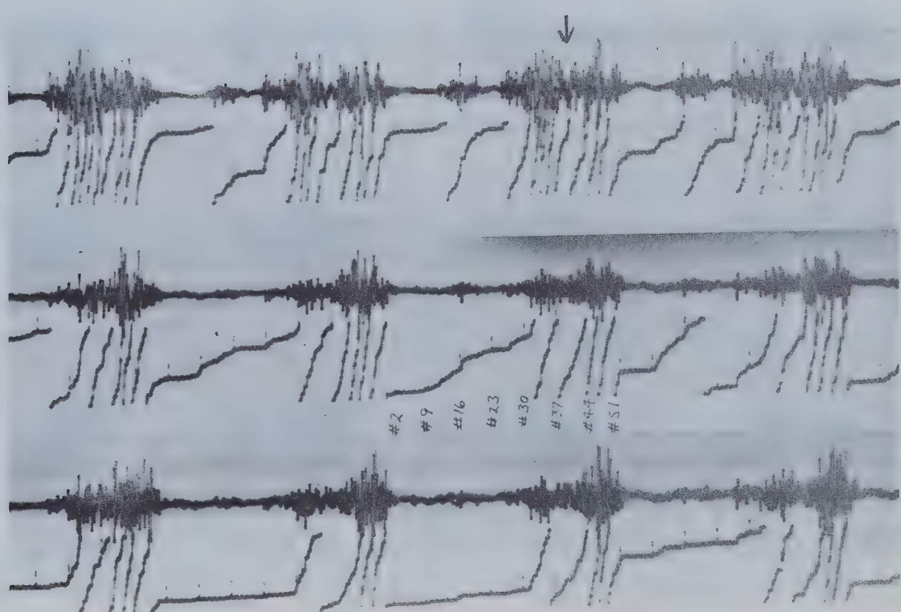


Figure 20. EMG and Area Summation - 11 mph (O.G.).

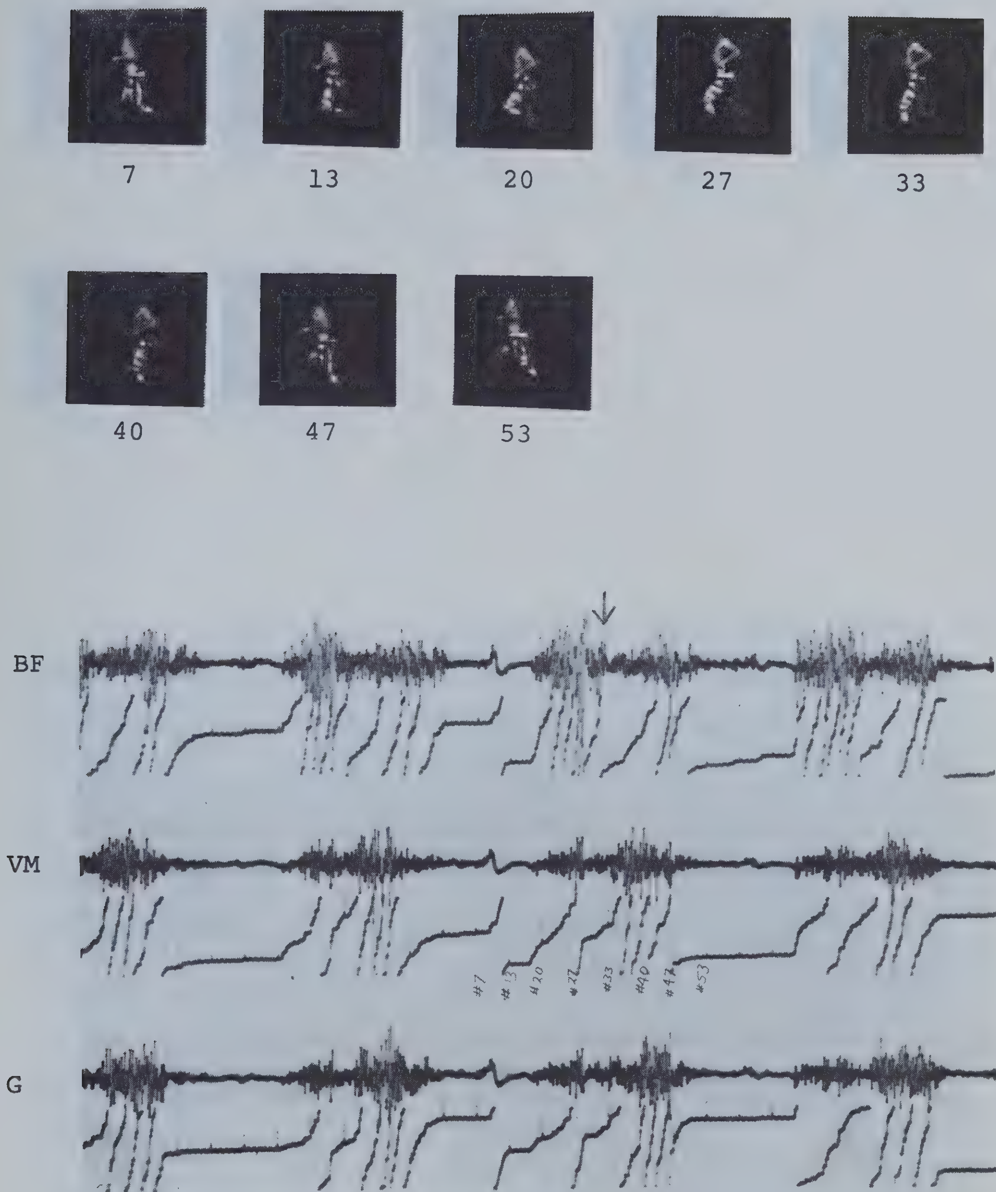


Figure 21. EMG and Area Summation - 5 mph (T.M.).

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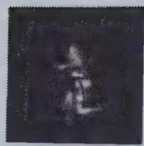

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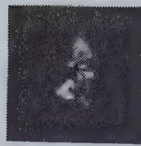

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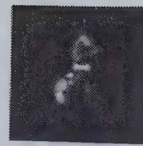

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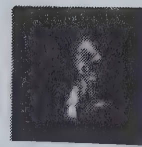

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38

45

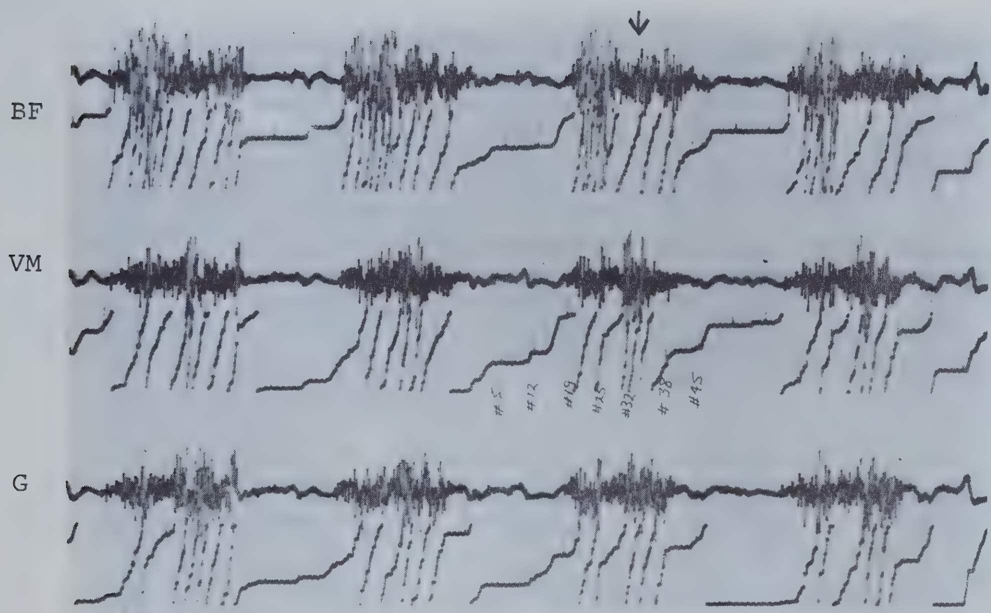
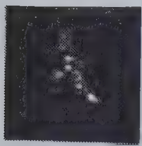


Figure 22. EMG and Area Summation - 9 mph (T.M.).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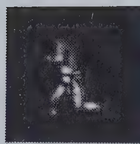
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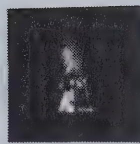
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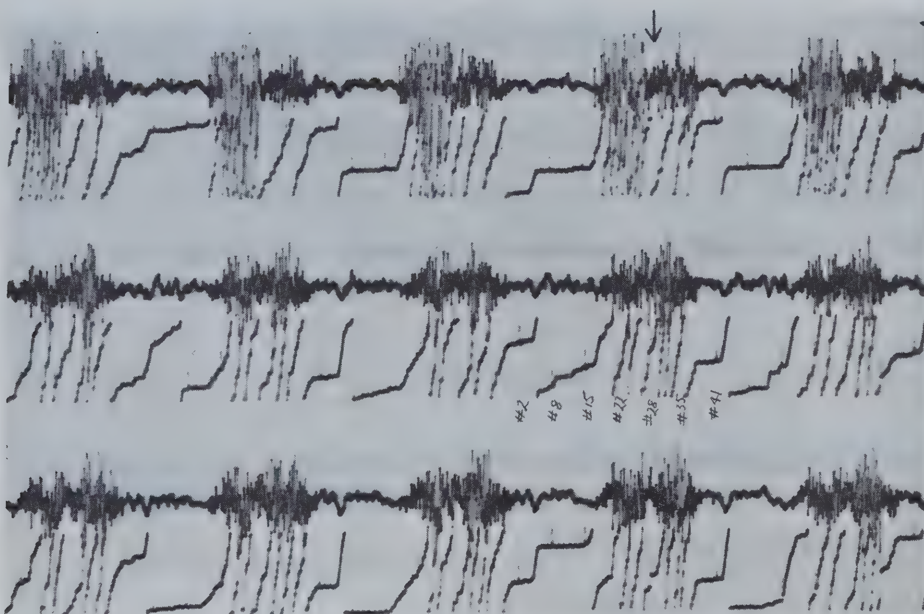

Figure 23. EMG and Area Summation - 11 mph (T.M.).

In order to have a relative quantitative measurement of the MAP for each muscle's performance, a highly sensitive 'area summator' was used. The number of 'resets' of the area summator gave a means of comparing the relative activity of a given muscle with itself. No attempt was made to gain an exact measurement of the muscle's action potential magnitude

A brief analysis was performed on each of the 'area summation' counts to determine whether there was any trend towards greater variability in MAP for either treadmill or overground running (see Appendix D).

Temporal Analysis of MAP For Treadmill and Overground Running

The periods of electrical activity and non-activity for one running stride were measured for each of the three muscles under the different running situations. The results were tabulated in Table IV.

DISCUSSION

Examination of Temporal Relationships Between Treadmill and Overgroung Running

It was found that the total time of one stride was greater for overground running as compared to treadmill running, at all three speeds. This meant that the stride frequency was greater and that the stride length was less for treadmill running at a given speed.

TABLE IV

TEMPORAL ANALYSIS OF EMG FOR TREADMILL AND OVERGROUND RUNNING

(ONE STRIDE)

Muscle	Running Classification	Active (sec.)	Non-Active (Sec.)	Total Time (sec.)
B.F.*	5 mph (O.G.)	.45 (54.2%)	.38 (45.8%)	.83
V.M.	5 mph (O.G.)	.45	.38	.83
G.	5 mph (O.G.)	.45	.38	.83
B.F.	5 mph (T.M.)	.50 (63.3%)	.29 (36.7%)	.79
V.M.	5 mph (T.M.)	.50	.29	.79
G.	5 mph (T.M.)	.50	.29	.79
B.F.	9 mph (O.G.)	.41 (55.4%)	.33 (44.6%)	.74
V.M.	9 mph (O.G.)	.40 (54.1%)	.34 (45.9%)	.74
G.	9 mph (O.G.)	.40	.34	.74
B.F.	9 mph (T.M.)	.38 (55.1%)	.31 (44.9%)	.69
V.M.	9 mph (T.M.)	.34 (49.3%)	.35 (50.7%)	.69
G.	9 mph (T.M.)	.34	.35	.69
B.F.	11 mph (O.G.)	.40 (55.6%)	.32 (44.4%)	.72
V.M.	11 mph (O.G.)	.39 (54.2%)	.33 (45.8%)	.72
G.	11 mph (O.G.)	.39	.33	.72
B.F.	11 mph (T.M.)	.32 (54.2%)	.27 (45.8%)	.59
V.M.	11 mph (T.M.)	.31 (52.5%)	.28 (47.5%)	.59
G.	11 mph (T.M.)	.31	.28	.59

*Biceps Femoris (B.F.); Vastus Medialis (V.M.); Gastrocnemius (G.).

This finding was in agreement with Dal Monte et al. (1973) but was contrary to the study published by Nelson et al. (1972) who reported that treadmill running was characterized by lower stride frequency and greater stride length. A possible explanation for this would be that the runner, in landing on the ball of his foot for treadmill running, had to flex the knee. This flexion of the knee would mean a shorter reach of the forward leg.

For the three speeds of 5, 9 and 11 mph, it was also found that the percent time in contact with the running surface was slightly greater for treadmill running as compared to overground running (see Table II). This is in agreement with the study by Nelson et al. (1972). A possible explanation for this was that the subject found that he did not have to project his center of gravity to the same height as he would if he were running at a similar speed overground. Instead, he could 'balance' on the treadmill belt as it passed beneath him.

As would be expected, the percent time in the air increased for both conditions of running as the running speed was increased.

The percent time spent in the phases of mid-support and take-off decreased as the speed of running increased for both types of running. For the other four phases of running, the percent time increased with an increase in speed. The reason for this relative increase in time during these

stages was that the amplitude of angular leg movement increased with speed. This meant that the leg had to move through a greater angular distance during those phases of running.

Examination of Spatial Relationship Between Treadmill and Overground Running

It was found that the vertical fluctuation of the subject's center of gravity was greater for overground running as compared to the treadmill running, at all three speeds. It was also evident from the results that the amount of vertical flucuation tended to decrease for both treadmill and overground running as the speed of running increased (see Table III). A possible explanation for this observation would be that the subject, for overground running, tended to flex the ankle, knee, and hip joints more during the support phase in order to place the muscles of the leg segments in a position where they could exert a greater dynamic vertical force. As was stated previously, the subject propelled his center of gravity to a greater vertical height for overground running.

From the graphical analysis of the joint angles of the left leg for the different classifications of running, the following observations were made:

Hip Angle. At the end of the forward swing phase there was a more pronounced fluctuation in the extension of the hip for overground running as compared to treadmill running,

at all three speeds (see Figures 6, 7, and 8). At the end of the forward swing, the degree of hip flexion was greater for overground running as compared to treadmill running. This effect was more noticeable at the two higher speeds. The reason for this fluctuation was probably due to an effort being applied by the right leg at the same moment in time. However, since the right leg was not analysed this question could not be answered.

At the end of the foot descent phase, the degree of hip extension was greater for overground as compared to treadmill running. This observation seemed peculiar at first, especially since the subject's stride length was known to be greater during overground running. A greater stride length at a given speed would mean that the forward leg reach of the runner was greater in overground running. One might then assume that the greater the forward reach, the greater would be the degree of hip flexion. The explanation for this lies in the fact that the subject landed on the balls of the feet during treadmill running, and on the heel of the foot during overground running. In order to land on the ball of the foot, the runner flexed the knee which in turn caused the thigh to be lifted. This lifting of the thigh decreased the angle at the hip.

During the foot-strike phase, there was noticeable hip angle fluctuation. This hip angle fluctuation tended to increase with speed for overground running, and decrease with

speed for treadmill running. The cause of this difference could most likely be attributed to the landing on the ball of the foot in one situation, and on the heel in the other.

The final phase of hip extension commenced during the early stages of mid-support for both methods of running.

For the follow through phase, there was greater extension of the hip for overground running as compared to treadmill running. This result would be expected since it would mean a greater stride length for any given speed.

Knee Angle. The degree of knee flexion, during the forward swing phase, was much more pronounced for overground running as compared to treadmill running (see Figures 9, 10, and 11).

During the later stages of foot descent, the knee was extended more for overground running than for treadmill running. There was a noticeable fluctuation in knee angle at foot-strike for overground running. This result again would be due to landing on the heel as compared to the ball of the foot.

The final phase of knee extension began in the later stages of mid-support for both treadmill and overground running.

Knee extension during the take-off phase appeared to be slightly greater for overground running. This result would be expected since it would be hip extension which primarily made the difference in stride length.

Ankle Angle. During the forward swing phase, it was found that ankle extension (i.e. dorsal extension of the foot) was greater for overground running than for treadmill running. The reason for this finding was that there was greater ankle extension at take-off for overground running, and this ankle extension was maintained throughout the initial stages of forward swing.

The first major differences in ankle extension was noticeable during the later stages of foot descent. For treadmill running, the ankle was extended just before foot strike, whereas in overground running the foot became progressively more flexed as foot-strike approached (see Figures 12, 13, and 14).

At the point of foot-strike, the ankle was rapidly extended in overground running until the entire foot was fixed on the ground. For treadmill running this effect was not present since the subject had landed on the ball of the foot and not the heel. As would be expected, the ankle angle at the foot-strike for treadmill running was much greater than it was for overground running.

The ankle angle was consistently greater for treadmill running throughout the mid-support phase. This greater degree of ankle extension was caused by the runner remaining slightly on the balls of the feet throughout the entire period of mid-support.

Examination of the Timing Sequence of the Leg Joints

From Figures 15, 16 and 17, it was possible to

determine the relative joint coordination of the left leg for both treadmill and overground running.

It was observed for both methods of running that the initiation of hip extension preceded the initiation of knee extension, which in turn preceded the initiation of ankle extension at take-off.

During the forward swing, maximum knee flexion was achieved before maximum hip flexion. By the time maximum hip flexion had occurred, the knee had already begun to extend.

Examination of the EMG Relationship Between Treadmill and Overground Running

It was found for both treadmill and overground running that the muscular activation of biceps femoris, vastus medialis, and gastrocnemius, commenced simultaneously. This simultaneous activation of these muscles was most likely due to the cocontraction of gastrocnemius and biceps femoris during knee extension in order to regulate the degree of knee bend.

For both overground and treadmill running, the termination of muscular activity was not completely simultaneous for the two faster speeds of running. For these speed the activity of biceps femoris lasted the longest, while the activation periods of vastus medialis and gastrocnemius tended to terminate simultaneously but sooner than biceps femoris. The longer activation period of biceps femoris would prolong hip extension and aid in the high backward

motion of the leg during follow-through.

At 5 mph, it appeared as though the termination of activity of these muscles was simultaneous. The reduced muscular effort, at the relatively low speed of 5 mph, would most likely be the cause of this observation.

The percent cycle of activation of the three muscles was examined for both treadmill and overground running (see Table IV).

For overground running, it was found that the percent cycle of activation tended to remain fairly constant at a value of about 55%.

For treadmill running at 9 and 11 mph, the percent cycle of activation was very close to the overground value of 55%. This may seem surprising at first since the percent time of support for treadmill running was consistently greater than for overground running. The explanation for this observation was that the muscle activity terminated before the foot had left the treadmill.

For the speed of 5 mph on the treadmill, the percent cycle of activity was found to be 63%. This value was considerably different from the value of 55% for overground running at 5 mph. This difference would seem to suggest that the subject was not running in as relaxed a manner for this low speed on the treadmill. The fact that the subject was running on the balls of the feet, and that the stride length was shorter, would tend to support this suggestion.

The following observations were made for each of the three muscles through examination of their respective EMG tracings:

Biceps femoris (overground running). It was observed for overground running that the first burst of major electrical potential commenced during the initial stages of foot descent. This was the stage where the thigh had reached its maximum amplitude and was beginning to descend. Thus biceps femoris was not used to decelerate the thigh during the forward swing stage. Gravitation force would most likely be responsible for the deceleration of the thigh during forward swing. Biceps femoris played an active part in the downward acceleration of the thigh which aided the extension of the lower leg during the foot descent phase.

There was a distinct period of reduced muscular activity commencing at the end of foot descent and continuing into the foot-strike phase. This result would most likely be due to the subject maintaining an extended leg position in order to land on the heel of the foot first.

During the period of mid-support there was a second burst of major electrical activity which coincided with the beginning of the powerful hip extension phase at take-off. This phase terminated just after take-off.

For the faster speeds of 9 and 11 mph, a small burst of electrical activity was noticeable during the middle stage of the forward swing. This burst of electrical

activity coincided with the period of maximum knee flexion for the left leg. The electrical activity in biceps femoris would suggest that the high degree of flexion maintained at the knee joint was not just a result of the forward acceleration of the thigh. As will be mentioned again later, this phase of electrical activity was not observed for treadmill running at any of the three speeds.

Biceps Fermoris (treadmill running). It was observed for treadmill running that the first burst of major electrical activity commenced during the final stages of forward swing. The initial occurrence of electrical activity was sooner than for overground running. The explanation would seem to be that the runner was hurrying the termination of the swing phase so as to prepare for foot-strike. Thus it would appear that the subject's running manner was not as relaxed for treadmill running.

There was no distinct interval of reduced muscular activity separating the two major stages of EMG. The second stage of this muscular activity remained at a fairly constant level which was lower than the level of the first stage. The second stage commenced immediately after the first stage had terminated. The termination of the first stage was near the end of foot descent. The termination point of the second stage of activity was at the end of the take-off stage.

As was mentioned previously, there was no evidence of any muscular activity occurring during the forward swing phase.

A possible explanation for this result was that the treadmill's backward action on the lower leg, coupled with the forward acceleration of the thigh, supplied enough whiplike action to bring the knee into an adequate flexed position for forward swing. As was noted earlier, the extent of knee flexion during this stage was considerably less than for overground running. The combination of these two points would tend to support the finding of no detectable electrical activity in biceps femoris during this stage.

Vastus medialis (overground). It was observed for overground running that the first stage of major electrical activity commenced during the initial stages of foot descent. This stage terminated just after foot-strike. The electrical activity in vastus medialis during this stage would certainly indicate that it played an active part in the extension of the knee during foot descent.

Unlike biceps femoris, there was no distinct interval of reduced electrical activity beginning at the end of foot descent and continuing into the foot-strike phase. This observation would suggest that the subject was maintaining a fairly constant muscle tension to keep the leg extended for foot-strike.

The second stage of activity was distinctly greater than the first, and commenced during the initial stages of mid-support. The second stage, as would be expected, reached peak activity at the point of transition from knee flexion

to knee extension during the middle stage of mid-support. The termination of the second stage occurred just after takeoff.

Occasionally, for the speed of 11 mph, a quite small burst of electrical activity was observed during the forward swing. Bier and Ralston (1965) have pointed out that the classic stretch reflex does not occur during a passive limb movement. This conclusion would indicate that vastus medialis was helping to control the degree of knee flexion during the forward swing at 11 mph.

Vastus medialis (treadmill running). It was observed for treadmill running that as the speed of running increased, the EMG signal from vastus medialis tended to merge into a single stage of electrical activity.

The initiation of this single stage of electrical activity occurred at the end of the forward swing. This commencement of electrical activity in vastus medialis for treadmill running was earlier than the activation of vastus medialis for overground running. This result would indicate that the subject was hurrying the forward extension of the leg in preparation for foot-strike.

A peak interval of activation occurred early in the mid-support phase. The peak interval coincided with the transition from knee flexion to knee extension during the period of mid-support.

The termination of the activity of vastus medialis

occurred during the initial stages of the take-off phase. This result would suggest that the push-off from the treadmill was not as explosive as it was for overground running. It would seem that the treadmill carried the leg backwards during the final stages of take-off and that vastus medialis had relaxed.

Gastrocnemius (overground running). It was observed for overground running that the electrical activity appeared to occur in two stages with a major and a minor stage of activity. Unlike biceps femoris, there was no distinct interval of reduced electrical activity between the two stages. The overall impression was that the EMG followed very closely the EMG pattern generated by vastus medialis.

The first stage of minor activity commenced during the initial stages of foot descent and terminated at the end of the foot-strike. The electrical activity in gastrocnemius during foot descent would seem to indicate that the muscle was preparing for foot impact even before foot contact had been made. Thus the muscle activity at this stage would seem to be a learned response. Also, it would control the degree of knee flexion.

The second stage, which was the major stage of electrical activity, commenced at the end of foot-strike and terminated just after take-off.

A peak interval of activation occurred during this second stage. The peak interval coincided with the initiation

of ankle extension at the beginning of take-off.

It was of interest to note that the peak interval of activity for gastrocnemius appeared slighty after the peak interval of vastus medialis and biceps femoris. This observation would suggest that the powerful action of hip and knee extension was initiated with the heel fixed on the ground. The fact that the heel was fixed on the ground during the initiation of hip and knee extension would seem very efficient since it would mean that the ground would stabilize the foot and would offer greater support than gastrocnemius could provide if the heel were off the ground during this stage. If the ankle were allowed to flex during the early stages of hip and knee extension, the large force generated by the hip and knee extension would be partially lost, and the take-off would not be as efficient.

Gastrocnemius (treadmill running). It was observed for treadmill running, as it was for overground running, that the EMG of gastrocnemius followed very closely the EMG pattern generated by vastus medialis.

The initiation of electrical activity occurred at the end of the forward swing and terminated during the initial stages of the take-off phase. This initiation of electrical activity in gastrocnemius for treadmill running was earlier than the activation of gastrocnemius for overground running. As was mentioned previously for overground running, the most likely reason for this result was that the subject

was hurrying the extension movement of the lower leg in preparation for landing. The activation of gastrocnemius during foot descent would indicate that it was involved in controlling the extension of the ankle.

The peak period of electrical potentials occurred in the early stages of mid-support. This observation was a direct result of the subject landing on the balls of his feet when running on the treadmill. The continuously high activity of gastrocnemius throughout the support phase could be attributed to the fact that the subject remained on the ball of his foot throughout this stage. Remaining on the ball of his foot throughout this stage would subject the gastrocnemius to additional stress during the powerful hip and knee extension phase at take-off.

The early termination of the electrical activity in gastrocnemius, before the foot had left the treadmill, would indicate that the push-off was not as explosive an effort as for overground running. This conclusion is strengthened by the observation that the subject's center of gravity did not reach the height that it did for overground running.

Examination of the Variability of the MAP for Treadmill and Overground Running

There appeared to be a trend towards greater MAP variability during treadmill running as compared to overground running (see Appendix D). However, the sample size, from which the variability of MAP was examined, was too small to form any really definite conclusion.

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY

The purpose of this study was to examine whether the muscular pattern, as well as the temporal and spatial relationship of a runner's legs in overground running was duplicated when running on a treadmill at the same speed.

One volunteer male subject, who was in excellent running condition, was used. The subject was familiarized with the task over a period of three training sessions.

Three muscles of the subject's left leg were wired for EMG. These muscles were: (1) biceps femoris of the hamstring group, (2) vastus medialis of the quadriceps group, and (3) gastrocnemius of the calf muscle group.

The subject performed at three speeds in the gymnasium. The gymnasium running was referred to as 'overground' running. The subject's EMG patterns for the above mentioned muscles were recorded, and then synchronized with the corresponding leg positions, with the aid of cinematography.

The subject then performed on the treadmill at speeds which were matched as close as possible to the actual speeds of 5, 9, and 11 mph used in the gymnasium. The subject was filmed and a recording was made of the EMG patterns of the same three leg muscles.

The temporal and spatial relationships of overground

and treadmill running were examined by plotting the joint angles of the left leg against time. Also, the subject's center of gravity displacement was plotted against time.

The electromyographical patterns generated from biceps femoris, vastus medalis, and gastrocnemius were compared, for one running stride, at three different speeds, for both overground and treadmill running. A temporal analysis was performed on the electromyographical signals so as to determine the percent cycle of electrical activity.

CONCLUSIONS

Within the delimitations of the design of this study and the limitations of the acquisition of the data, the following conclusions were drawn:

1. For a given speed, the stride frequency was greater and the stride length was less for treadmill running (Table II).

2. For the speeds of 5, 9, and 11 mph, the percent time that the subject was in contact with the running surface was greater for treadmill running as compared to overground running. This difference tended to increase with speed (Table II).

3. The percent time that the runner spent in the air increased for both treadmill and overground running as the speed of running was increased (Table II).

4. The percent time spent in the phases of mid-support and take-off decreased as the speed of running increased for both types of running. For the phases of forward swing, foot

descent, foot-strike and follow-through, the percent time spent in each increased with an increase in speed (Table II).

5. The vertical fluctuation of the subject's center of gravity was greater for overground running at all three speeds. The amount of vertical fluctuation tended to decrease for both treadmill and overground running as the speed of running increased (Table III).

6. At the end of the forward swing phase there was a more pronounced fluctuation in the extension of the hip for overground running as compared to treadmill running at the three speeds tested (Fig. 6, 7, 8).

7. The degree of hip flexion at the end of the forward swing phase was greater for overground running at the three speeds tested. This effect increased with an increase in running speed (Fig 6, 7, 8).

8. The degree of hip extension at the end of the foot descent phase was greater for overground running at the three speeds tested (Fig. 6, 7, 8).

9. There was a noticeable hip angle fluctuation during the foot-strike phase which tended to increase with speed for overground running and decrease with speed for treadmill running (Fig. 6, 7, 8).

10. There was greater hip extension during follow-through for overground running as compared to treadmill running at the three speeds tested (Fig. 6, 7, 8).

11. The degree of knee flexion during the forward swing

phase was greater for overground running at the three speeds tested (Fig. 9, 10, 11).

12. The knee was extended more during the later stages of foot descent for overground running at the three speeds tested (Fig. 9, 10, 11).

13. The degree of knee extension during the take-off phase was greater for overground running at the three speeds tested (Fig. 9, 10, 11).

14. Ankle extension during the forward swing phase was greater for overground running than for treadmill running at the three speeds tested (Fig. 12, 13, 14).

15. For treadmill running, the ankle was extended during the later stages of foot descent. For overground running the foot became progressively more flexed as foot-strike approached. This was noted for the three speeds tested (Fig. 12, 13, 14).

16. The degree of ankle extension throughout the mid-support phase was greater for treadmill running at the three speeds tested (Fig. 12, 13, 14).

17. For both treadmill and overground running at take-off, the initiation of hip extension preceded the initiation of knee extension, which in turn preceded the initiation of ankle extension (Fig. 15, 16, 17).

18. For both treadmill and overground running, maximum knee flexion was attained about half way through the forward swing stage. At the end of forward swing, when maximum hip

flexion occurred, the knee had already begun to extend (Fig. 15, 16, 17).

19. For both treadmill and overground running the muscular activation of biceps femoris, vastus medialis, and gastrocnemius commenced simultaneously (Fig. 18-23 inclusive).

20. For both treadmill and overground running at the speeds of 9 and 11 mph, the activation periods of vastus medialis and gastrocnemius tended to terminate simultaneously but earlier than the activation period of biceps femoris. At the speed of 5 mph the termination of electrical activity of these three muscles was simultaneous (Fig. 18-23 inclusive).

21. For overground running the first sign of electrical activity in biceps femoris appeared during the initial stages of foot descent. This meant that biceps femoris was not used to decelerate the thigh during the forward swing stage. For treadmill running, biceps femoris was active at the end of forward swing which meant that it aided in the deceleration of the thigh (Fig. 18-23 inclusive).

22. Peak electrical potentials for biceps femoris were achieved during the powerful hip extension phase which occurred in the final stages of mid-support (Fig. 18-23 inclusive).

23. For the speeds of 9 and 11 mph in overground running, biceps femoris played an active role in maintaining the high degree of knee flexion during forward swing. This result was not observed for treadmill running (Fig. 19, 20).

24. For both treadmill and overground running, vastus medialis played an active role in the extension of the knee during foot descent. The period of peak activity for vastus medialis was attained at the point of transistion from knee flexion to knee extension for both treadmill and overground running (Fig. 18-23 inclusive).

25. Vastus medialis played an active role in controlling the degree of knee flexion during the forward swing phase at 11 mph for overground running. This result was not observed for treadmill running (Fig. 20).

26. For treadmill running, the electrical activity generated from biceps femoris, vastus medialis, and gastrocnemius terminated before take-off was completed. For overground running the electrical activity from these muscles did not cease until after take-off (Fig. 18-23 inclusive).

27. The electromyographical pattern produced by gastrocnemius was very similar to the electromyographical pattern of vastus medialis for both overground and treadmill running (Fig. 18-23 inclusive).

28. The electrical activity in gastrocnemius during foot descent for both treadmill and overground running, indicated that gastrocnemius was being prepared for foot strike even before impact had occurred (Fig. 18-23 inclusive).

29. The peak period of activity in gastrocnemius for overground running, coincided with the initiation of ankle extension at the beginning of take-off. The peak period of

activity in gastrocnemius, for treadmill running, appeared early in the mid-support phase. For both treadmill and overground running, the peak period of activity in grstrocnemius appeared after the peak period of vastus medialis and biceps femoris (Fig. 18-23 inclusive).

30. There appeared to be a trend towards greater MAP variability during treadmill running as compared to overground running (Table VI, VII).

It appears as though there are sufficient qualitative differences in the EMG pattern and joint angles of the leg to question the practice of using the treadmill as a training device for overground running in the training of track athletes.

RECOMMENDATIONS

1. That a further analysis be undertaken to determine the intra-individual variance. This could be approached by studying:

   a) a greater number of running strides.

   b) a greater number of trials over a number of days.

2. In order to move towards a general conclusion which would allow one to state the degree of running simulation provided by the treadmill, one should examine a larger number of subjects. Also, the different classes of running should be examined. This would include sprinters, middle distance, and long distance runners.

3. In order to be able to perform the required analyses on a large number of subjects, a method of converting the analogue information to digital should be devised so that the data can then be analysed by computer methods.

Another step which would save time in the analyses would be to develop a technique whereby the time base of one joint angle plot could be synchronized with that of another. A quick visual analysis by superimposing one leg angle graph on to another could then be made. This might be achieved by using a foot switch which is triggered when the foot first contacts the ground. The switch would then be used to activate a camera system which had a constant frame rate.

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APPENDIX A

EMG APPARATUS

4- Channel E.M.G. system*

\# FOUR INDEPENDENT LOW-NOISE PREAMPLIFIERS.

Each preamplifier contains 4 matched, selected low-noise field-effect transistors, in a balanced differential A.C. - coupled circuit featuring high common-mode rejection. Low-noise deposited carbon resistors and mylar capacitors are used.

\# Electrodes removable from subject with a single plug.

Each pair of E.M.G. electrodes is supplied with a special Common-mode balancing circuit which permits the operator to compensate for differences in skin-contact resistance, tissue impedance, electrode impedance, and minimizes the usual effects of electrolytic action or contact potentials developed at the electrode skin interface. As a result, surface skin electrodes can be used under most conditions, minimizing discomfort associated with subcutaneous needles.

\# SINGLE CABLE TO CENTRAL LOCATION Carries information on all 4 muscles.

This cable is driven by a special ultra-low impedance circuit, featuring 4 pairs of matched, balanced, differential low-noise emitter followers and a 50 - ohm driver transformer for each of the four channels. As a result, long cables can be used without degrading the signal quality, and crosstalk and interaction between the channels is undetectable. Additional lengths of cable up to 100 ft can be added without impairing the signals detected at the receiving end. Also, the low output impedance and relatively high level of the signal before it enters the cable is compatible with the future addition of a 4 - channel F.M. transmitter and telemetry system, to eliminate the requirement for even one cable.

\# NO BLOCKING OR OFFSET PROBLEMS:

Many popular E.M.G. Preamplifiers, such as the Grass P 15, are prone to an annoying total blockage of the signal following a high-level input signal, such as occurs when the subject or experimenter touches one electrode. Those circuits exhibit a fairly long period of time during which no information can be recorded and the experimenter must wait until the circuit stabilizes itself before he can proceed with the data collection. The new F.E.T. differential preamplifier circuitry developed here has a sufficiently wide dynamic range and rapidly enough equilibrating time constants that this effect is not seen. As a result, the experimenter may record continuously, without interruptions due to blocking.

\# STANDARD 9 - VOLT TRANSISTOR RADIO BATTERIES USED.

These batteries are sufficiently standardized, easily obtained, and inexpensive, that it is considered preferable to simply install a new battery before a major data collection period, and be sure of battery condition. Battery should be replaced when it falls below 8 volts, but the very low drain of the remote circuit should permit long battery life. The use of a D.C. power supply at both remote transponder and central location permits total freedom from Power lines, desirable for safety considerations, and also to eliminate hum problems entirely, as in a free-field situation away from power lines completely.

* As written by the designer, Dean Charles, dept. of Physiology, University of Alberta.

* SIMPLIFIED OPERATION:

Attention is directed to the Physiological phenomena being recorded instead of to the equipment being used. It is extremely difficult to make hum-free recordings of muscle groups in large animals in an environment saturated with 60-cycle hum. Nevertheless, the entire circuitry, time constants, and human-engineering design of this system is directed at the simplification and dependability of relatively untrained personnel recording muscle groups from large animals in an unrestrained situation. Thus, the minimum number of controls are provided, and all controls required to optimize the recording of muscle activity and exclude interference are already included, and where practical, are pre-set.

The operation is directed at timing of various muscle groups, rather than a measure of signal amplitude in absolute terms. Therefore, amplitude and gain calibration are made continuously variable, so that differences from subject to subject may be smoothly expanded to fill a full trace on the recording charts being used.

If calibration is required, it is a simple matter for the user to adjust the continuously-variable gain controls against a known external signal source, to set the gain of the equipment at any desired preset level. When this has been done, the knobs should not be touched; alternatively, a marker may be set on the knob to permit return to a given gain setting. This system has the additional advantage that gain does not need to be 1, 10, 100 or 1000, but may be whatever value takes advantage best of the dynamic range available on the recording device, and may be set to be different on each channel as required.

* BUILT-IN AUDIO AMPLIFICATION CHANNEL:

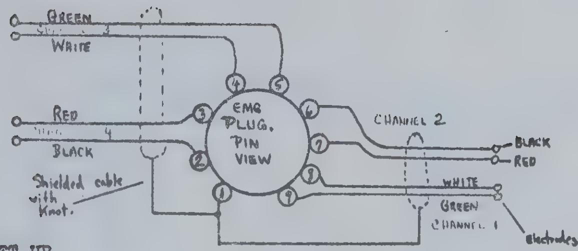
Simplifies operation by eliminating the requirement to connect an additional audio amplifier for monitor of E.M.G. versus Hum. Simplifies the positioning and choice of E.M.G. electrode placement. Permits use of any standard Headphones out in the field, away from power lines without additional auxiliary equipment.

THE SAME SWITCH THAT CONTROLS THE METER ALSO CONTROLS THE HEADPHONES. Thus, the operator has co-ordinated audio-visual information on the placement and proper signal output of any set of electrodes. A rapid and easy comparison of the activity of any muscle group compared to any other muscle group may be done simply by turning the knob to select which channel is to be monitored. 1, 2, 3, or 4.

The sounds which appear in the headphones correspond to the signal shown on the meter.

* LOW-IMPEDANCE, WIDE OUTPUT SWING, VARIABLE LEVEL OUTPUTS. (4) FOUR INDEPENDENT.

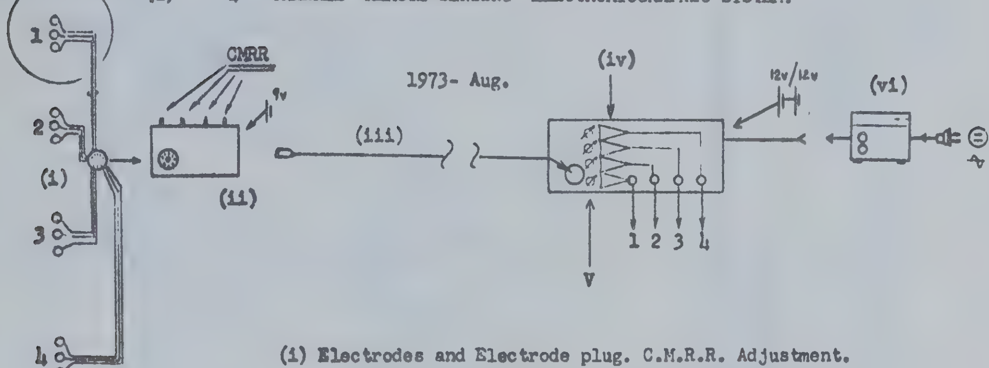
The outputs are 160 ohms, capable of a full 20 volt peak to peak swing, if required, and will drive low-sensitivity tape recorders or chart recorders to full excursion with ease. Hundreds of feet of shielded cable may be hung on these outputs without degrading signal quality if the situation demands. Each output is totally and completely independent of the others, and is unaffected by the position of the METER and HEADPHONE MONITOR Switch. All inputs and outputs operate continuously, and there is no time-sharing or time-division multiplexing, hence there is no ultrasonic component in the output to cause problems with beats or oscillations in tape recorder equipment. All four outputs may be used at once or any combination thereof.



SET-UP

INSTRUCTIONS

(1) 4 - CHANNEL REMOTE-SENSING ELECTROMYOGRAPHIC SYSTEM.



(i) Electrodes and Electrode plug. C.M.R.R. Adjustment.

(ii) Remote transponder unit with single-cable output.

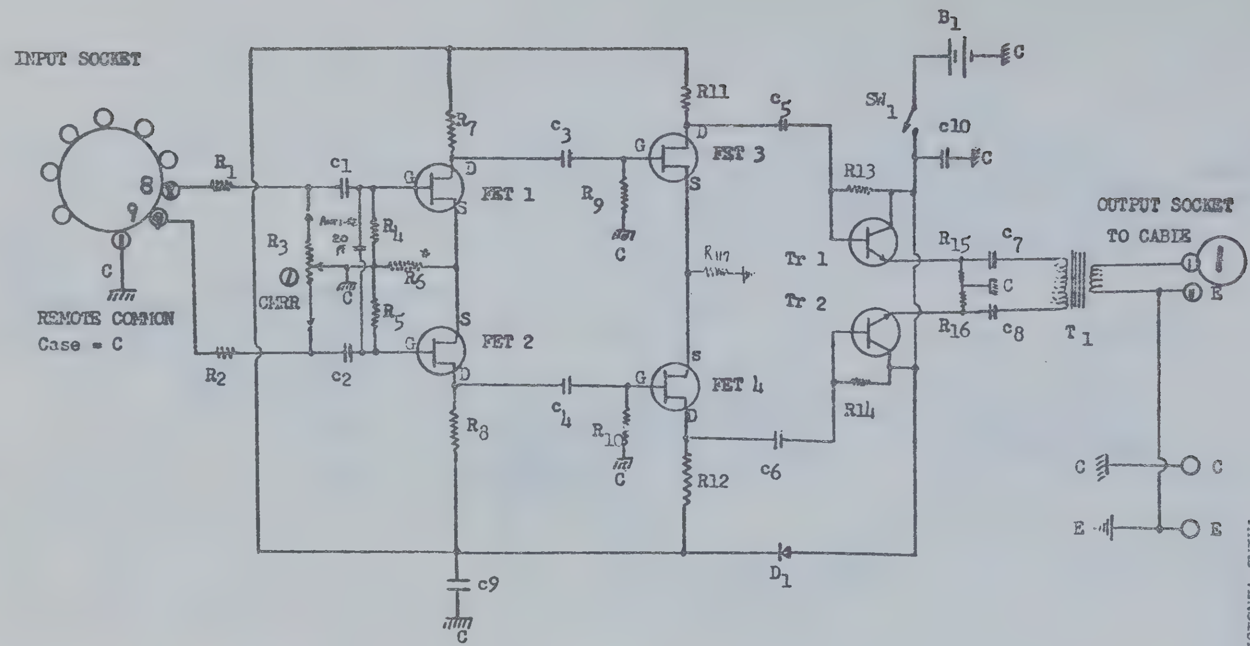
(iv) Active Filter Assembly for rejection of A.C. 60 - Hz Hum.

(V) Bandpass filters, 4 Adjustable Gain preset calibrators, 1 meter calibrator and channel select switch, 1 Monitor output jack and headphone preamp built-in.

(vi) Operation from matching Power-supply or D.C. Batteries in open-field situation. (No power connection needed for free-field operation.)

(vi) FOUR INDEPENDENT DISCRETE OUTPUTS, Not multiplexed: Each output is ON at all times, free of discontinuities or switching transients.

THIRD VERSION (DIFFERENTIAL)



SCHEMATIC DIAGRAM OF CHANNEL NUMBER 1 IN REMOTE TRANSPONDER UNIT.

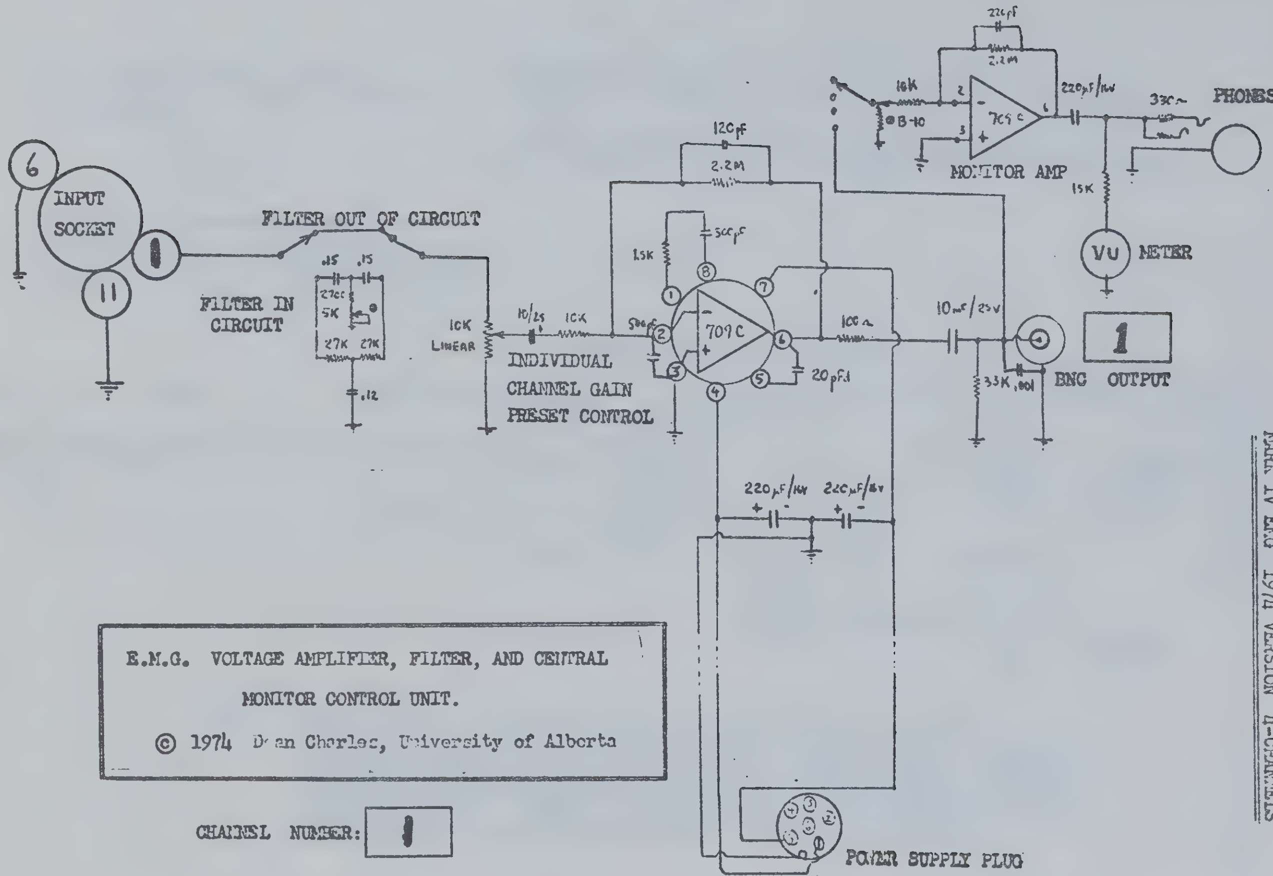
R_1 = Rid List

(FOUR IDENTICAL CHANNELS)

HUM-CANCELLING DIFFERENTIAL PREAMPLIFIER

Note: FET's 1 to 4 in each channel are 2N 3819's selected from top 10% of production run for low noise and VGS.

MARK IV EMG 1974 VERSION 4-CHANNELS



E.M.G. VOLTAGE AMPLIFIER, FILTER, AND CENTRAL MONITOR CONTROL UNIT.

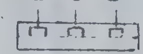
© 1974 Dean Charles, University of Alberta

CHANNEL NUMBER: 1

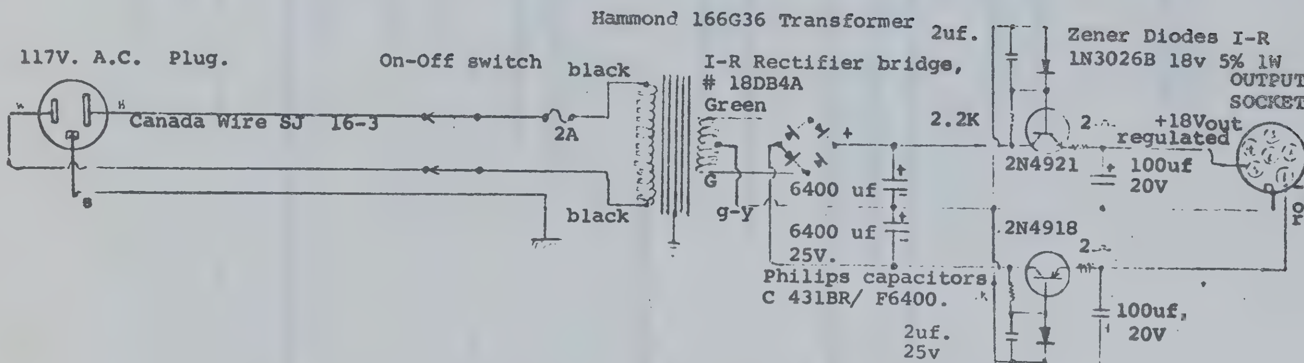
SCHEMATIC DIAGRAM & PARTS LIST OF ZENER STABILISED DUAL D.C. POWER PACK FOR FOUR-CHANNEL F.E.T. PREAMP.

CUSTOM DESIGNED BY DEAN CHARLES, JULY 1970, FOR Dr. STEIN AND DR. K.G. PEARSON, DEPT. OF PHYSIOLOGY.

Leads facing viewer with the imprinted identification number facing upwards.



Terminal arrangement of Motorola plastic Silicon power transistors.
2N 4918 - PNP 40V 1-3 Amperes h_{fe} 20.
2N 4921 + NPN 40V 1-3 Amperes h_{fe} 20.



NOTE: POWER SUPPLY INCORPORATES LINE-VOLTAGE REGULATION AND LOAD-VARIATION REGULATION, BUT DOES NOT HAVE AUTOMATIC SHUTDOWN IN CASE OF SHORT CIRCUITS CAUSED BY THE EXPERIMENTER. THEREFORE, PLEASE NOTE THAT THIS POWER SUPPLY IS NOT INTENDED FOR GENERAL LABORATORY USE. PLEASE DO NOT CONNECT ANYTHING ELSE TO IT BUT THE UNIT FOR WHICH IT WAS DESIGNED, AND WHICH IT MATCHES.

SECOND VERSION

SPECIFICATIONS:

Supply voltage range, Preamp remote unit....................................9.5V to 8.0 V loaded

Supply voltage range, Central monitor amplifier............................+ 16.0-0 -16.0 max
+ 10.0-0 -10.0 min.

Input impedance of monitor amplifier.. 10K Bridging input.

Preamplifier input impedance with CMRR adjustment connected as supplied.....500K x 2

Preamplifier input impedance with CMRR adjustment disconnected............. 2.7 Megohms / input

Preamplifier input impedance with CMRR removed and R4-R5 at 100 meg each...50 Megohms per input

Remote transponder cable-driving output impedance per output ....50 Ohms. (balanced)

Output impedance of system at BNC connectors.............................150 Ohms

Voltage gain of system.............................continuously variable from 0 to 2000

Voltage gain of 100...1.7 dial setting ch 4.

Typical EMG input signal from Biceps at input electrodes..................... 25 mV P-P.

Typical noise level referred to equivalent input noise........................ .1 mV P-P.

Signal-to-noise ratio... 250

Bandwidth at 3 dB down points filter "OFF".................................. 20 Hz - 2000 Hz

Bandwidth at 3 dB down points filter "ON" .... 100 Hz - 2000 Hz

Maximum output swing of Monitor amplifiers................................. 20 V P-P

Maximum background noise level of Monitor amplifier per channel any setting.... 2 mV P-P

Common-Mode-rejection-ratio.. 50 DB

Maximal expected noise level at output....................................... 100 mV

60 Hz rejection at filter... 30 dB min.

APPENDIX B

PROGRAM TO CALCULATE LEG ANGLES

```
C     PROGRAM TO CALCULATE ANGLE OF HIP,KNEE AND ANKLE FOR LEFT AND RIGHT LEGS
C     X AND Y ARE ARRAYS FOR X AND Y COORDINATES - NUMBER FROM 1-16
C     RESPECTIVELY THESE ARE EAR,R SHOULDER,R ELBOW,R WRIST,R FINGERTIPS,
C     L SHOULDER,L ELBOW,L WRIST,L FINGERTIPS,CENTER HIP,R KNEE,R ANKLE,R TOE,
C     L KNEE,L ANKLE,L TOE
C
C     ANGLE IS AN ARRAY NUMBERING FROM 1-6
C     RESPECTIVELY THESE ARE: R HIP,R KNEE,R ANKLE,L HIP,L KNEE,L ANKLE
C
C     FOR LIMB ANGLES GREATER THAN 180 DEGREES,SUBTRACT THE VALUE FROM 180 DEGREES
C     AND THEN ADD 180 DEGREES
C
C
      DIMENSION X(16),Y(16),ANGLE(6)
   25 READ 50, IEV,IFR,(X(I),I=1,16),ITST,INO,ISP,IVAR,ITR,ISS,
     1(Y(I),I=1,16)
   50 FORMAT (I1,I4,3X,16(F3.2,1X),I1,I2,3I1,I2/8X,16(F3.2,1X))
      IF(X(1).EQ.0.) GO TO 1000
      IF(INO.NE.1) GO TO 20
      PRINT300
      PRINT 301
      PRINT 302
      PRINT 303
  300 FORMAT(' ',25X,'ANGLES ARE GIVEN IN DEGREES')
  301 FORMAT ('0',8X,'RIGHT',6X,'RIGHT',6X,'RIGHT',6X,'LEFT',7X,'LEFT',
     17X,'LEFT')
  302 FORMAT (9X,'HIP',8X,'KNEE',7X,'ANKLE',6X,'HIP',8X,'KNEE',7X,
     1'ANKLE')
  303 FORMAT (9X,'ANGLE',6X,'ANGLE',6X,'ANGLE',6X,'ANGLE',6X,'ANGLE',
     16X,'ANGLE')
```

```
C    RIGHT HIP
  20 TTX=(X(6)-X(2))/2.+X(2)
     TTY=(Y(6)-Y(2))/2.+Y(2)
     HYPA1=SQRT((TTY-Y(11))**2+(TTX-X(11))**2)
     HYPB1=SQRT((TTY-Y(10))**2+(TTX-X(10))**2)
     HYPC1=SQRT((Y(10)-Y(11))**2+(X(10)-X(11))**2)
     ANGLE(1)=57.3*ARCOS((-(HYPA1**2)+(HYPB1**2)+(HYPC1**2))/(2.
    1*HYPB1*HYPC1))
C    RIGHT KNEE
     HYPA2=SQRT((Y(10)-Y(12))**2+(X(10)-X(12))**2)
     HYPB2=SQRT((Y(11)-Y(12))**2+(X(11)-X(12))**2)
     HYPC2=SQRT((Y(10)-Y(11))**2+(X(10)-X(11))**2)
     ANGLE(2)=57.3*ARCOS((-(HYPA2**2)+(HYPB2**2)+(HYPC2**2))/(2.*
    1HYPB2*HYPC2))
C    RIGHT ANKLE
     HYPA3=SQRT((Y(11)-Y(13))**2+(X(11)-X(13))**2)
     HYPB3=SQRT((Y(11)-Y(12))**2+(X(11)-X(12))**2)
     HYPC3=SQRT((Y(12)-Y(13))**2+(X(12)-X(13))**2)
     ANGLE(3)=57.3*ARCOS((-(HYPA3**2)+(HYPB3**2)+(HYPC3**2))/(2.
    1*HYPB3*HYPC3))
C    LEFT HIP
     HYPA4=SQRT((TTY-Y(14))**2+(TTX-X(14))**2)
     HYPB1=SQRT((TTY-Y(10))**2+(TTX-X(10))**2)
     HYPC4=SQRT((Y(10)-Y(14))**2+(X(10)-X(14))**2)
     ANGLE(4)=57.3*ARCOS((-(HYPA4**2)+(HYPB1**2)+(HYPC4**2))/(2.*
    1HYPB1*HYPC4))
```

```
C     LEFT KNEE
      HYPA5=SQRT((Y(10)-Y(15))**2+(X(10)-X(15))**2)
      HYPB5=SQRT((Y(14)-Y(15))**2+(X(14)-X(15))**2)
      HYPC5=SQRT((Y(10)-Y(14))**2+(X(10)-X(14))**2)
      ANGLE(5)=57.3*ARCOS((-(HYPA5**2)+(HYPB5**2)+(HYPC5**2))/(2.*
     1HYPB5*HYPC5))
C     LEFT ANKLE
      HYPA6=SQRT((Y(14)-Y(16))**2+(X(14)-X(16))**2)
      HYPB6=SQRT((Y(14)-Y(15))**2+(X(14)-X(15))**2)
      HYPC6=SQRT((Y(15)-Y(16))**2+(X(15)-X(16))**2)
      ANGLE(6)=57.3*ARCOS((-(HYPA6**2)+(HYPB6**2)+(HYPC6**2))/(2.*HYPB6*
     1HYPC6))
      PRINT400,IFR,(ANGLE(J),J=1,6)
  400 FORMAT('0',I3,4X,6(F6.2,5X))
      GO TO 25
 1000 PRINT1001
 1001 FORMAT('1','END')
      STOP
      END
```

APPENDIX C

CALCULATION OF RUNNING SPEED (GYMNASIUM)

CALCULATION OF RUNNING SPEED (GYMNASIUM)

The frame rate for speed setting #1 and #3 was found to be 70 fps. The frame rate for speed setting #2 was found to be 69 fps. The frame rate of filming for all trials on the treadmill was found to be 66 fps.

Speed Setting #1

From the film it was found that the subject's center of gravity moved a horizontal distance of 6.04 ft. in a time interval of 58 frames (0.83 sec.). This resulted in an average speed of 4.97 miles per hour. Thus speed setting #1 was found to be very close to the desired 5.0 miles per hour. The percent error was 0.60%.

Speed Setting #2

The horizontal distance, which the center of gravity travelled in a time interval of 0.75 sec., was found to be 10.12 feet. This resulted in an average speed of 9.20 mph. As a result of this, speed setting #2 was used as 9.0 mph and not the 8.0 mph which was previously desired. The percent error from 9.0 mph was 2.22%.

Speed Setting #3

From the film analysis it was found that the runner's center of gravity had a horizontal displacement of 11.89 ft.

in a time interval of 0.74 sec. This meant an average speed of 10.95 mph. Thus speed setting #3 was very close to the desired 11.0 mph. The percent error was 0.45%.

APPENDIX D

ANALYSIS OF MAP VARIABILITY FOR TREADMILL
AND OVERGROUND RUNNING

ANALYSIS OF MAP VARIABILITY FOR TREADMILL AND OVERGROUND RUNNING

The numbers of 'resets' of the area summator were counted up for as many complete leg cycles as possible for each classification of running. In the case of overground running, only those EMG signals that were produced during the period of near constant speed were analysed.

The standard deviation (SD) from the mean was then calculated for all three muscles under each classification of running (Table V).

The average standard deviation (SD) of the three muscles was then calculated for all three speeds of running under the two conditions (Table VI).

In addition to this, the average standard deviation was calculated for each muscle for the three speeds of running. A comparison was then made between the average standard deviation for treadmill and overground running (Table VIII).

TABLE V

VARIABILITY OF MAP FOR TREADMILL AND OVERGROUND RUNNING

Muscle	Running Classification	Area Summation Counts	S.D.
B.F.	5 mph (O.G.)	4.75; 4; 5; 5; 5.25; 5; 4.25; 5	.432
B.F.	9 mph (O.G.)	8; 8.5; 9; 8.5; 7.5; 7	.736
B.F.	11 mph (O.G.)	9.25; 8.5; 8.75; 9; 9	.285
V.M.	5 mph (O.G.)	4; 4; 4; 4; 4; 3.5;3.75; 3.5	.229
V.M.	9 mph (O.G.	5.25; 4.75; 5.25; 5; 5; 4.5;	.318
V.M.	11 mph (O.G.	5.25; 5.25; 4.75; 5; 5;	.209
G.	5 mph (O.G.)	2.5; 2; 2; 3; 3; 2.25; 1.75; 2.5	.463
G.	9 mph (O.G.)	5; 4; 4; 4; 4; 3.5	.492
G.	11 mph (O.G.)	4.75; 3.75; 4.5; 4.25; 4.5	.326
B.F.	5 mph (T.M.)	6.5; 8.25; 8.5; 6.5; 6.5; 8.75; 8; 9; 8.75	1.06
B.F.	9 mph (T.M.)	11; 11.5; 11.5; 11; 11.5; 10.25; 10; 9; 11	.848
B.F.	11 mph (T.M.)	10.25; 10.5; 10.75; 10; 10; 10; 10.5; 10.5; 10	.292
V.M.	5 mph (T.M.)	5; 5; 4.75; 4.5; 5; 5; 5; 4.5; 5.5;	.306
V.M.	9 mph (T.M.)	6.25; 6; 7; 8; 6.5; 7.25; 5.5; 6; 6;	.781
V.M.	11 mph (T.M.)	6; 7; 7; 6.75; 6; 6;6; 7; 6;	.500
G.	5 mph (T.M.)	5; 5.75; 5.25; 4.25; 5; 5; 5; 5.25; 4.25	.475
G.	9 mph (T.M.)	6; 6; 7.5; 7; 5; 7; 5.5; 5; 5.5	.917
G.	11 mph (T.M.)	7; 6.5; 6.5; 6; 6.75; 7.25; 7; 7.25; 6.75	.404

TABLE VI

AVERAGE STANDARD DEVIATION ($\overline{SD}$) OF MAP

FOR DIFFERENT SPEEDS OF RUNNING

(TREADMILL VS OVERGROUND)

Running Speed (mph)	Muscles	$\overline{SD}$ (Overground)	$\overline{SD}$ (Treadmill)
5	B.F., V.M., G.	.375	.614
9	B.F., V.M., G.	.515	.849
11	B.F., V.M., G.	.273	.399

TABLE VII

AVERAGE STANDARD DEVIATION ($\overline{SD}$) OF MAP

FOR INDIVIDUAL MUSCLES

(OVERGROUND VS TREADMILL)

Muscle	Running Speeds (mph)	$\overline{SD}$ (Overground)	$\overline{SD}$ (Treadmill)
B.F.	5, 9, 11	.484	.733
V.M.	5, 9, 11	.252	.529
G.	5, 9, 11	.427	.599